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Operational Energy in Historic Religious Buildings: A Qualitative Approach

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Abstract: Typically, operational energy is approached and evaluated from a quantitative point of view and, to a large extent, according to life cycle assessment (LCA). This article seeks to develop a qualitative approach to assess the past operational energy of a historic religious building in the province of Quebec, Canada. We propose a method for determining the past thermal sensation of individuals residing in a monastery by evaluating this sensation using the thermal sensation vote (TSV) related to the predicted mean vote (PMV). Doing so allows us to infer the operational temperatures and setpoints, providing an additional indicator of energy consumption. The proposed method is based on the identification and analysis of individual perceptions contained in archive documents, facilitating the reconstruction of the expressed thermal sensation and of a TSV index. The method is deployed on a prospective basis, enabling the creation of a chronological series designed to exhaustively document the thermal sensation during heating periods. This article contributes to discussions among critics who have observed a mismatch between TSV indices and PMV parameters and prognosis. It also brings us closer to a finer understanding of thermal comfort and the use/consumption of operational energy in historic religious buildings.

Keywords: operational energy; qualitative method; thermal sensation vote (TSV); predicted mean vote (PMV); historic religious building

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1. Introduction

In the context of climate change, sustainable practices are essential for achieving the mitigation objectives established in the Paris Agreement. Because the construction and building industries play a significant role in global greenhouse gas (GHG) emissions, it is crucial that good sustainable practices are developed in these sectors in order to reduce their impact on the climate [1,2]. The construction industry is particularly problematic due to the environmental impact of material production and transportation [3]. Munarim and Ghisi (2016) [4] noted that construction processes in Canada contribute to 11 million tonnes of waste, account for 50% of natural resources use, and represent 52% of water consumption. Karoglou et al. (2019) [5] highlighted that these two sectors (construction and building) are responsible for 36% of the energy consumed worldwide and contribute to 40% of carbon dioxide (CO_2) emissions. According to Opher et al. (2021) [6], this last percentage has been increasing at a rate of 2% per year since 2017. This trend is attributed to the rise in floor space per person, population growth, and improved access to energy in developing countries. For these reasons, the construction industry is responsible for a significant carbon footprint.

These environmental issues regarding the building industry are attributed, in part, to the construction phase, which includes resource extraction, acquisition, and transportation, as well as the energy consumption of buildings during their operational phase (e.g., energy

used for heating, cooling, and lighting). Consequently, the operational energy of buildings has been extensively examined in the literature using various methods to assess different scenarios that could result in energy savings. These scenarios include various retrofitting or renovation options that even consider the rehabilitation of historic buildings rather than the construction of new ones [7–15].

From this perspective, for over a decade, a movement has advocated that the "greenest building is the one that you don't build" [16] (p. 1). According to this movement, historic buildings could be used to avoid the construction of new ones, and rehabilitation giving historic buildings a modern use would prove to be effective, energy-efficient, and sustainable. Such practices would allow for the reduction of the environmental impact due to the reuse and recycling of materials (including resources) [2–4,17–24], the diminution of transportation [17,23,24], and the decrease of operational energy [2–4,17,23–28].

Operational energy is central to the sustainability analysis of historic buildings, since it accounts for a large part of their carbon footprint. It plays an important role in several GHG quantification methodologies, notably life cycle assessment (LCA), which considers both present and past operational energy. However, assessing the past operational energy of a building is not a straightforward task. It is a challenge, as it requires research methods capable of estimating LCA parameters, which are often determined in a somewhat arbitrary manner based on present time realities.

Furthermore, to assess the operational energy of historic buildings, most research has used quantitative methods such as measurements and energy modelling [29–42]. In contrast, research using qualitative methods is scarce, with only a few studies relying on questionnaires and personal communication [43–46]. These studies do not cover past operational energy, as they focus on the present time. This article aims to address these gaps by proposing an approach designed to qualitatively assess the past operational energy of a historic religious building using archive documents.

2. Literature Review

2.1. Assessing Operational Energy Using Quantitative and Qualitative Methods

In the scientific literature, there are many quantitative ways of measuring the building industry's environmental impact. One of them is through LCA. This methodology provides information regarding the impact of a product or service throughout its life cycle, from cradle to grave [1,4,25,27,47–49]. It considers all the activities necessary to produce a certain product, each of which with an environmental impact: resource extraction and acquisition; means of transportation; manufacturing of all necessary materials; construction; upkeep; utilization of the final product; and its end of life (waste, recycling, and reutilization). LCA lists the construction materials and energy use in this production system, considering both embodied energy (the energy used from resource extraction to the end of a product's life) and operational energy (the energy used when utilizing the product, such as for heating and cooling) [2,50].

The results of LCA enable the comparison of various scenarios to determine, for instance, which has the lowest energy consumption and, consequently, the smallest environmental impact [4,10,48,49]. In this context, scholars have used LCA to assess how the rehabilitation or retrofit of a historic building could be more sustainable from an environmental point of view. Some examined specific features or upkeep aspects such as cleaning (equipment and solvents), painting (paint and renders), insulating materials (thermal insulation options), and alternative heating [7,51–53]. A few others adopted a holistic approach that considered the entire building. For instance, conservation, restoration, and renovation scenarios were compared through all the life cycle of the studied buildings [8,11,12,14,54]. Applying LCA to case studies, authors have also compared historic buildings to recent ones in order to determine the best sustainable option: their rehabilitation or newer constructions [2,9,10,13,25,50,55].

Other than utilizing LCA, scholars have assessed the operational energy of historic buildings through other means, primarily employing quantitative methods such as field

measurements, computer simulations, and energy modelling. This kind of research, in contrast to LCA, focuses solely on the current operational energy and lacks a historical perspective. Most rely on case studies and aim to compare various retrofitting scenarios to determine the most sustainable option [29,33,38,40,41]. Authors have also compared the current energy usage of historic buildings, either to the predicted energy usage after implementing retrofitting strategies or to the energy usage of the modern version of the same type of building (e.g., comparing the energy consumption of historic residential buildings to modern residential buildings) [34–37,39,42].

Fewer studies have employed qualitative methods to assess the operational energy of historic buildings. These studies are summarized in Table 1. We accessed these articles through the databases Web of Science, Science Direct, and Sofia (the catalog of Quebec universities) using the following keywords: operational energy AND historic buildings, operational energy AND qualitative methods, and operational energy AND qualitative methods AND historic buildings. The selected articles were chosen based on three criteria: (1) They employed a qualitative approach to assess the operational energy of buildings (using methods other than estimating the thermal sensation of the buildings' occupants, which will be discussed in Section 2.2), (2) the methodology was sufficiently detailed, and (3) the method was applied to historic buildings. Due to the lack of qualitative research assessing the operational energy of historic buildings, these chosen articles offer a comprehensive representation on the subject.

It was observed that, when using a qualitative method, many gaps remained regarding its precise implementation [43–46]. As an example, De Berardini et al. (2014) [44] proposed interventions to improve the energy efficiency of historic buildings in the Abruzzo Region of Italy. In doing so, these authors combined the quantitative method of thermography testing with the qualitative one of a direct survey. The specific details of this qualitative method were scarcely provided in the article. In order to evaluate thermal comfort and energy consumption in a mosque in Turkey, Diler et al. (2021) [45] used both a quantitative method (long-term measurements) and a qualitative one involving the collection of data on the building, including its structural characteristics and thermal properties. These data were gathered through surveys, reports, and personal communication, although limited information was provided regarding their exact implementation. Spigliantini et al. (2018) [46] developed a complex qualitative method primarily centred on semi-structured interviews with managers or owners of historic buildings to investigate energy-saving measures. However, their article placed more emphasis on the development of this method than its practical application. Using a qualitative approach, Akande et al. (2016) [43] assessed the operational energy of reconverted churches in the United Kingdom. To gather information on these churches, they administered questionnaires to the buildings' owners or managers who were required to respond in person. This method examined many variables, such as building characteristics, energy-using systems, utilization of these systems, energy consumption, energy management, and users' behaviour. Nevertheless, not all of them were thoroughly analyzed in the article and users' behaviours were ultimately not discussed.

It is worth mentioning that these different application perspectives within historic buildings reflect the main approaches to studying operational energy on a broader level. Chau et al. (2015) [56] identified three major approaches to studying operational energy, each of which has its own characteristics and challenges: (1) an approach that studies the operational energy based on actual consumption, which requires continuous access to information (e.g., fuel bills); (2) an approach that seeks to establish a uniform level of operational energy consumption based on architectural references specific to given categories of buildings (e.g., residential, commercial, institutional, etc.); and (3) a dynamic approach that aims to establish current and past operational energy consumption according to a number of variables, both objective/quantitative (e.g., outdoor temperature) and qualitative (e.g., users' behaviour).

Table 1. Qualitative methods employed in the literature for assessing the operational energy of historic buildings.

Author(s)	Objective(s)	Method(s)			Period	Type(s) of Historic Building(s)
		Description of the Method(s)	Type(s) of Qualitative Analysis	Variables		
Akande et al., 2016 [43]	To assess the operational energy use of historic buildings to increase their sustainable performance.	Case studies of 8 refurbished and converted churches in the United Kingdom. Field surveys and questionnaires administered to the building managers mixed with desk study.	Questionnaires administered to the building managers and interviews.	• Building characteristics (e.g., type, occupancy, maintenance) • Energy using equipment (e.g., lighting, refrigerating, heating) • How equipment is used (e.g., hours of operations, control) • Energy used (e.g., energy consumption data, energy management practices) • Energy management options (e.g., actions taken to improve energy performance, policies) • Behaviour (e.g., actions taken to control the users' behaviour)	Current (12-month period)	Religious buildings (listed churches)
De Berardinis et al., 2014 [44]	To describe a study of historic buildings and propose interventions to improve their energy efficiency.	Study of buildings in various small towns of Abruzzo Region, Italy. On-site investigations and thermography testing to acquire data on thermal quantities and assess thermal loss of these buildings.	Direct survey using environmental diagnostic systems.	• Factors related to solar radiation and ventilation	Current	Residential buildings
Diler et al., 2021 [45]	Three objectives: 1. to investigate thermal comfort during prayer times for one year in a historic mosque, 2. to assess its energy consumption, 3. to perform risk assessment study to preserve its cultural heritage value.	Case study of the Ulu Mosque, Manisa, Turkey. Long-term measurements of indoor and outdoor climatic conditions (temperature and relative humidity) mixed with collection of data on structural characteristics of the building.	Data collection on the building from architectural and restoration projects, reports, books, surveys, and personal communication with staff of the mosque.	• Structural characteristics of the building • Thermal properties of building materials • Heating/cooling system • Ventilation strategies • Number of occupants and occupation time	Current (two-year period)	A religious building (a mosque)
Spigliantini et al., 2019 [46]	To outline a methodology that allows to investigate the potential of energy and economical savings by acting only on the use of the historic building.	Two case studies: 1. The National Gallery of Umbria, Perugia, Italy and 2. Turin Conservatory of Music (University of Music), Italy. Consists of semi-structured interviews with the building managers or owners and quantitative questionnaires with the building occupants.	Semi-structured interviews with the building managers or owners.	• General information (e.g., entire conditioned surface of the building, number and location of thermal zones, opening hours) • The way the building is managed (e.g., windows, internal/external doors, shading) • System management (e.g., type of heating, ventilation and air conditioning (HVAC) systems) • Energy costs (e.g., energy bills) • Occupants of the buildings (e.g., relations between the managers/technicians and the occupants regarding eventual problems)	Current (18-month period)	An art gallery and a university

Martinez-Molina et al. (2016) [57] pointed out that there are different typologies to take into account when studying the energy consumption of historic buildings. They highlighted that, in this respect, buildings of a religious nature (churches, convents, monasteries, etc.) must be considered separately from other historic buildings, for example, those with residential use, because they feature unique characteristics (e.g., very large common areas and extra thickness of walls and foundations). Lidelöw et al. (2019) [58] concurred, noting that religious historic buildings have not been sufficiently studied in terms of energy consumption.

In this article, we will focus on historic religious buildings, drawing from a broader theoretical framework related to historic buildings, as there is currently no dedicated theoretical corpus devoted specifically to historic buildings of a religious nature.

Thus, this literature review demonstrates that most research assessing the operational energy of historic buildings relies on quantitative methods, while qualitative methods are rarely employed. When employed, two limitations can be identified: (1) they focus on current (rather than past) energy consumption, and (2) some gaps in their implementation remain. This paper aims to address those gaps and develop a qualitative approach for estimating the past operational energy of historic religious buildings.

2.2. Assessing Operational Energy Based on Thermal Comfort

Another way of qualitatively assessing the operational energy of a historic building is by considering the thermal comfort of individuals using it [59,60]. This type of comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment" [58] (p. 12).

Thermal comfort was initially estimated using Fanger's predicted mean vote/predicted percentage of dissatisfaction models (PMV/PPD). The PMV model was based on laboratory experiments conducted with participants positioned in the controlled environment of climate chambers [59–61]. Conducting these experiments, objective and physical data were combined with subjective ones that focused on participants' perceptions. Objective data were obtained by measuring operative temperature (which regroups indoor air temperature and radiant temperature), air speed, humidity, clothing insulation, and metabolic rate influenced by physical activity. Subjective data were acquired by administering questionnaires to participants to assess whether they felt satisfied or not in different thermal contexts, such as when the temperature rises or falls several degrees. These questionnaires included the thermal sensation vote (TSV), which is defined as a subjective index that monitors the actual thermal sensation of individuals. Participants can indicate their thermal sensation on a seven-point scale that ranges from cold (−3) to cool (−2), slightly cool (−1), comfortable/neutral (0), slightly warm (+1), warm (+2), and hot (+3) (Table 2) [62–66]. TSV can vary from one participant to another according to many factors other than environmental ones, such as their physiology (e.g., age, gender, and weight); their psychological disposition (e.g., emotions); their exposure time (short term or long term); and their behavioural adaptation (e.g., clothing) [67–69].

Table 2. The seven-point scale of the thermal sensation vote (TSV) [62–64,66,67,69].

Seven-Point Scale	Thermal Sensation
−3	Cold
−2	Cool
−1	Slightly cool
0	Neutral/Comfortable
+1	Slightly warm
+2	Warm
+3	Hot

What resulted from these experiments was a complex equation that can now be used to estimate the thermal sensation in a building according to objective and physical

data (PMV = 0.303e(−0.036·M)) + 0.028) (M − W) (where M = metabolic rate and W = mechanical work) [59]. Thus, when a researcher has these objective data, the PMV equation enables the estimation of the average thermal sensations experienced by individuals in a studied building. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), defined the PMV as "[a model] that predicts the mean value of thermal sensation votes of a large group of persons, expressed on a seven-point scale" [70]. We used the definition provided by ASHRAE, because these standards are compatible with an online tool that allowed us to estimate the operational energy of a building (CBE Thermal Comfort Tool), which will be discussed later.

According to ASHRAE standards, an acceptable PMV, meaning the zone where most individuals feel comfortable, is situated between −0.5 and +0.5. If the PMV is higher than +0.5, individuals are deemed to be warm or hot, and if it is lower than −0.5, they are deemed to be cool or cold. It must be specified that the thermal comfort measured by the PMV will not be entirely consensual: it pertains to the greatest number of individuals. There can be a certain proportion of them who will not be satisfied with the thermal environment and who will complain. This specific proportion can be calculated using PMV's corollary PPD (PPD = 100 − 95e(−0.03353·PMV^4 − 0.2179·PMV^2). If the PMV is at 0, the corresponding PPD will be 5%, meaning that 5% of individuals will be dissatisfied with the thermal environment [59,65,66,68,69,71–73].

Since its development, the PMV has become a widely used model, and as mentioned by Nicol et al. (2012) [73] (p. 44), "it forms the basis for most national and international comfort standards". However, its complexity may limit its use. To facilitate the applicability of this model and to easily calculate the PMV, a free and online tool was developed within the Center for the Built Environment (CBE) of the University of California Berkeley: the CBE Thermal Comfort Tool [74,75]. It made the PMV more accessible to a wide range of users.

Despite the usefulness and the accessibility of this model, it also possesses its limits. One of these limits is the sole consideration of the heat balance, meaning that an individual is supposed to feel comfortable if a balance is achieved between the heat produced by their body and the heat lost to the surrounding environment [73,76,77]. However, as noted by Nicol et al. (2012) [73], it is possible to reach this heat balance and still not feel quite comfortable, for instance, if the heat produced by a person's body equals the heat loss but is not evenly distributed from head to toe. This kind of situation is not sufficiently covered by the PMV.

Another limit concerns radiant asymmetry, which involves the thermal exchanges of the human body with the environment considering the surrounding surfaces (e.g., walls and windows) [62,65]. When such surfaces are colder or warmer than room temperature, it might affect the thermal comfort of individuals, especially for those sitting near a cold wall or window. As mentioned by Gao et al. (2023) [78], the PMV does not take into account this radiant asymmetry.

Additionally, there is a discrepancy between the estimation established by the PMV and field measurements done in various studies [60,61,64,67,79,80]. Many authors have noted a statistically significant difference between the model's predictions and the actual thermal comfort perceived by individuals when their thermal sensation was studied using questionnaires [60,64,67,73,80]. As an example, Cheung et al. (2019) [60] argued that there was a sizable disparity between the model's thermal comfort predictions and the comfort perceived by individuals. Indeed, these authors noted that 34% of the model's predictions were incorrect and that, even in a neutral environment, it achieved a precision level of only 50% at best. Kuru and Calis (2017) [80] reached similar conclusions. Their study compared the PMV with the actual mean vote (AMV) that measures the actual sensations of individuals (e.g., based on surveys). According to their results, there was a statistically significant difference between the PMV and the AMV.

To overcome the limits faced by the PMV, another model was developed: the adaptive model. As noted by Humphreys et al. (2015) [81], this new model depends on field surveys

(both longitudinal and transversal) where researchers measured environmental parameters and asked participants to rate their thermal comfort on a scale. In contrast to the PMV that considers individuals as passive, it considers them as active and possessing various means of adaptation. Thus, if environmental parameters change (e.g., indoor or outdoor temperature) and individuals become uncomfortable, they will react and try to restore their comfort (e.g., by putting on more clothes) [60–62,82–86].

However, as for the PMV, the adaptive model also has its limits. For instance, while the PMV model can be applied to both air-conditioned and heated buildings, as well as naturally ventilated buildings, the adaptive model can only be applied to the latter. Therefore, for this model to work, no mechanical cooling system nor heating system should be in operation. Unlike the PMV, which does not take into consideration the outdoor temperature, the adaptive model does, and this temperature must range between 10 °C and 33.5 °C. These constraints regarding the temperature range in the application of the adaptive model greatly limit its use during the winter in cold environments [65,74]. For these reasons, the adaptive model is of little use in our research, as we focused on the province of Quebec, which is known for its harsh winters.

Thus, while acknowledging its limitations, our study will use the PMV and its corollary TSV that can be employed in cold climates. In the literature, the TSV has often been evaluated using questionnaire surveys inspired by the ASHRAE standard. These questionnaires typically included close-ended questions such as multiple-choice responses and judgment scales. Their aim was to gather data on participants, their clothing, their physical activity, and, primarily, their perceived thermal sensation [64,67,69,80,87,88]. For instance, Jia et al. (2023) [64] administered such questionnaires twelve times to 32 participants to assess their evaluation of thermal conditions in a factory building. The information collected included personal details (gender and age), clothing specifics (current clothing items), and votes regarding temperature (e.g., ranking perceived thermal sensation from hot to cold). Similarly, Lindberg et al. (2017) [69] employed questionnaires to gauge the thermal sensation of customers in a supermarket, during both winter and summer seasons. The data gathered consisted of activity level; current clothing; and perception regarding the indoor environment (e.g., temperature, air velocity, and humidity). Zhang et al. (2023) [67], for their part, asked questions on participants' personal information, subjective thermal evaluation, activity level, and clothing layers. In another study, Wang et al. (2023) [87] recorded passengers' thermal comfort at various locations in a metro station using questionnaires that included information on their age, sex, height, weight, number of years living in the surroundings, clothing, and perceptions on the thermal environment. Finally, in their literature review on the subject, Rupp et al. (2015) [89] noted that many studies were done to assess the thermal comfort of individuals in various kinds of buildings (e.g., kindergartens, schools, universities, offices, residences, healthcare facilities, and hostels) using both questionnaires mixed with measurements of various parameters.

In the current study, rather than relying on questionnaires, a new approach is developed; it focuses on the thermal sensation of individuals as recorded in archive documents. To our knowledge, no qualitative method currently exists that measures past thermal sensation using historical materials. Existing methods are limited to the present time and use questionnaires as data collection tools. Based on this historical thermal sensation, it will be possible to estimate the past operational energy of historic religious buildings more reliably than through inferences made from current data.

3. Materials and Methods

The qualitative method we propose aims to estimate the past operational energy of a historic religious building. It provides a complementary approach to quantitative analysis. From a qualitative perspective, the method seeks to go beyond the use of questionnaires, which have their limitations, for instance, their inability to document the past operational energy of buildings.

The method consists of identifying the building occupants' past perceptions of thermal comfort and translating these perceptions into the TSV scale. The method is structured around six major steps explained in the following sections (Figure 1).

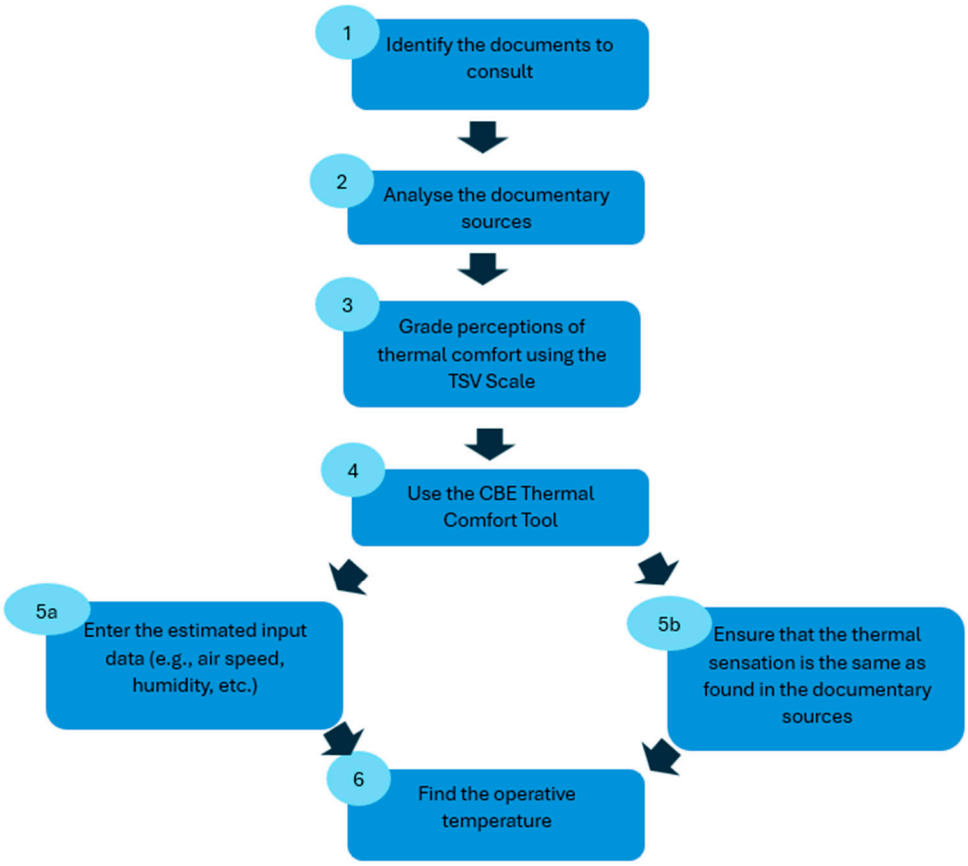


Figure 1. The six steps of our qualitative method.

3.1. Identifying Documentary Sources for Tracing Historical Perceptions of Thermal Comfort

As previously noted, contemporary questionnaires cannot trace past perceptions of thermal comfort, especially in historic religious buildings, as these perceptions are often rooted in long periods of time. To avoid anachronistic interpretations (e.g., those relating to contemporary times and contexts), it is crucial to identify documentary sources that are as reliable as possible. In this regard, our methodology suggests using a documentary source well suited for studying a historic religious building: the Annals of the religious community inhabiting it (step no. 1 of Figure 1).

Before going any further, it is necessary to provide a brief overview of the various types of religious buildings and the functioning of religious communities in order to understand the use and the significance of the Annals. Historic religious buildings are numerous. In the province of Quebec, Canada, there are almost 4000 historic religious buildings (Roman Catholicism). They include both churches, as well as conventual properties, such as convents, monasteries, and abbeys. Churches fall under the responsibility of the diocesan clergy and are generally not inhabited/visited on a full-time basis, except for the presbyteries (priests' residences) adjoining them. Conventual properties, for their part, belong to religious communities, which are large religious groups united by the vows of poverty, obedience, and chastity. Unlike churches, conventual properties are inhabited on an ongoing basis, which allows to estimate their past operational energy.

Within a religious community, communications are organized in a highly hierarchical manner. The fundamental orientations of communities are reported in their Constitutions and, at various times, specified in the documents presented by the members of the governing councils (including the superior) at general chapters. In contrast, the day-to-day life of

the community is recorded in a document called the Annals. The Annals correspond to a logbook kept by a member of the community, the annalist, who is specifically entrusted with this task. The mention of an element or event in the Annals of a religious community is not a random fact; it has a character of intentionality [90–92]. They are therefore archive documents that can be used to reconstruct the past thermal sensation of the religious community and then to estimate the past operational energy of the historic religious building it inhabited.

3.2. Analyzing Documentary Sources

The analysis of the documentary sources (step no. 2 of Figure 1) is divided into four interrelated parts. The first part consists of establishing the authenticity of the source to confirm that its written content is true [93]. In the case of the Annals, authenticity depends on the location of the document: it must be kept in an archive that is recognized by the religious community [94]. In most cases, religious communities have their own repositories. Less frequently, their archives are kept in institutional repositories, which possess one or more holdings specifically dedicated to religious communities.

The second part involves identifying the author, which is always the congregation's annalist. The challenge lies in identifying the potential presence of multiple authors within the same archive collection. Indeed, the Annals are presented as an almost daily chronicle of community life, though they are compiled into collections that sometimes span several years. As a result, the annalist may change over the years. This identification is important, since each annalist has their own style of writing and vocabulary for reporting on community life.

The third part consists of establishing the nature of the perceptions conveyed in the Annals. Sometimes, the annalists express themselves in a personal manner, which can be identified with the use of the first-person singular ("I"). More frequently, the annalist's writings reflect collective perceptions expressed in the first-person plural ("We"). In our research, these collective perceptions are of paramount importance, because they are widely shared among many members of the religious community.

Finally, the fourth part focuses on identifying the collective perceptions of thermal comfort as recorded in the Annals. Subsequently, we need to classify these perceptions into two types: (1) perceptions that directly express thermal comfort (e.g., "it is cold") and (2) perceptions that only indirectly express thermal comfort (e.g., "we are running low on coal for heating"). The aim of this classification is to identify and prioritize perceptions that are useful in our study, with a preference for direct perception due to their greater evocative power. However, since thermal comfort is only one out of many subjects recorded in the Annals of a religious community, we must sometimes rely on indirect perceptions.

3.3. Grading Perceptions of Thermal Comfort Using the TSV Scale

The third step (step no. 3 of Figure 1) involves grading perceptions of thermal comfort based on the seven-point TSV scale. This scale was chosen because it aligns with the purpose of our research and is compatible with both the CBE Thermal Comfort Tool and the ASHRAE standards. Using other scales would have posed additional challenges. For instance, it would have been difficult to use the McIntyre index, which comprises only a three-point scale based on temperature preferences (cooler, no change, and warmer). As noted by Humphreys and Hancock (2007) [95], using this scale makes it impossible to assess how much cooler or warmer a person would prefer. Thus, it has limited utility for estimating the operational energy of a religious historic building based on the nuns' perception of thermal comfort.

Perhaps it would have been possible to use the Bedford scale, which ranges from +3 (much too warm) to −3 (much too cool). According to Deb and Ramachandraiah (2010) [96], it is possible to establish a correlation between this scale and the seven-point TSV scale. Nonetheless, as mentioned earlier, the TSV scale remains most compatible with the CBE Thermal Comfort Tool, justifying its use. It is also worth noting that Sharifi et al.

(2021) [97] developed a novel and more precise numerical scale to assess an individual's thermal sensations, ranging from 1 (worst thermal condition) to 10 (best thermal condition). However, this research is still at an experimental stage and does not enable correlations with the qualitative perception of thermal comfort, as found in the Annals (e.g., it is difficult to determine what could be considered as a worst thermal condition based on the annalist's writings). Additionally, this new scale is not compatible with the CBE Thermal Comfort Tool.

Returning to our third step, gradation is based on the perceptions identified previously in the Annals. These perceptions, whether direct (preferably) or indirect, must be placed within their thermal context, meaning that the researcher must be able to put them in relation to the evolution of heating methods and major periods of building transformation. Otherwise, it may be difficult to properly explain the factors influencing annalists' perceptions (Figure 2).

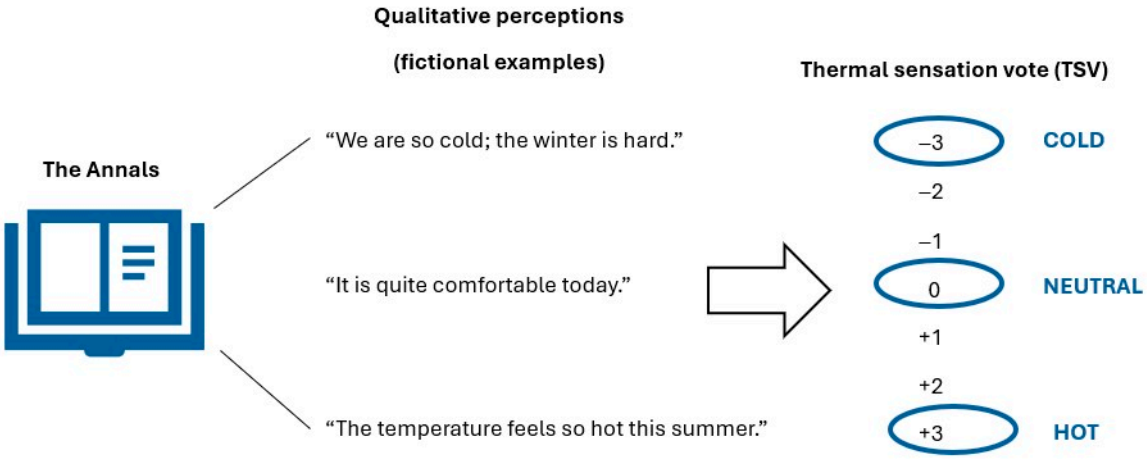


Figure 2. Interpretation of the thermal sensation vote (TSV) according to the Annals (fictional example).

After determining the TSV using the Annals, we compared it to the PMV to infer the possible operative temperature. To do so, we used the online CBE Thermal Comfort Tool (steps no. 4, no. 5, and no. 6 of Figure 1). Before going any further, we must clarify the relationship between the operative temperature (mean value of the air temperature and mean radiant temperature) and the operational energy (energy consumed in the building). Historic buildings are equipped with very few energy-consuming devices. Therefore, the energy used to operate these buildings primarily comes from the heating system. The heating system compensates for the heat loss of the building, which is closely related to the temperature gradient between the inside and outside during the heating season. The greater the temperature difference, the more energy the heating system consumes to maintain the thermal comfort of the occupants. A higher setpoint inside the building accentuates the temperature difference between the inside and outside, resulting in an increase in the energy used for heating [98,99].

To go back to the CBE Thermal Comfort Tool, it allows users to view a psychrometric chart by adding input data such as the operative temperature, air speed, relative humidity, metabolic rate, and clothing level. The X-axis of the chart represents the operative temperature, while the Y-axis represents the humidity ratio. Additionally, placing a cursor on a specific point (X, Y) on the chart displays the corresponding PMV and thermal sensation. For instance, the default PMV is set at −0.16, indicating a neutral sensation at an operative temperature of 25 °C (Figure 3). In our research, we lacked the operative temperature data (as it was our objective to estimate this temperature in historic religious buildings). Therefore, we used the chart, and the inferred thermal sensation based on the nuns' Annals to estimate this input data, rather than the reverse process.

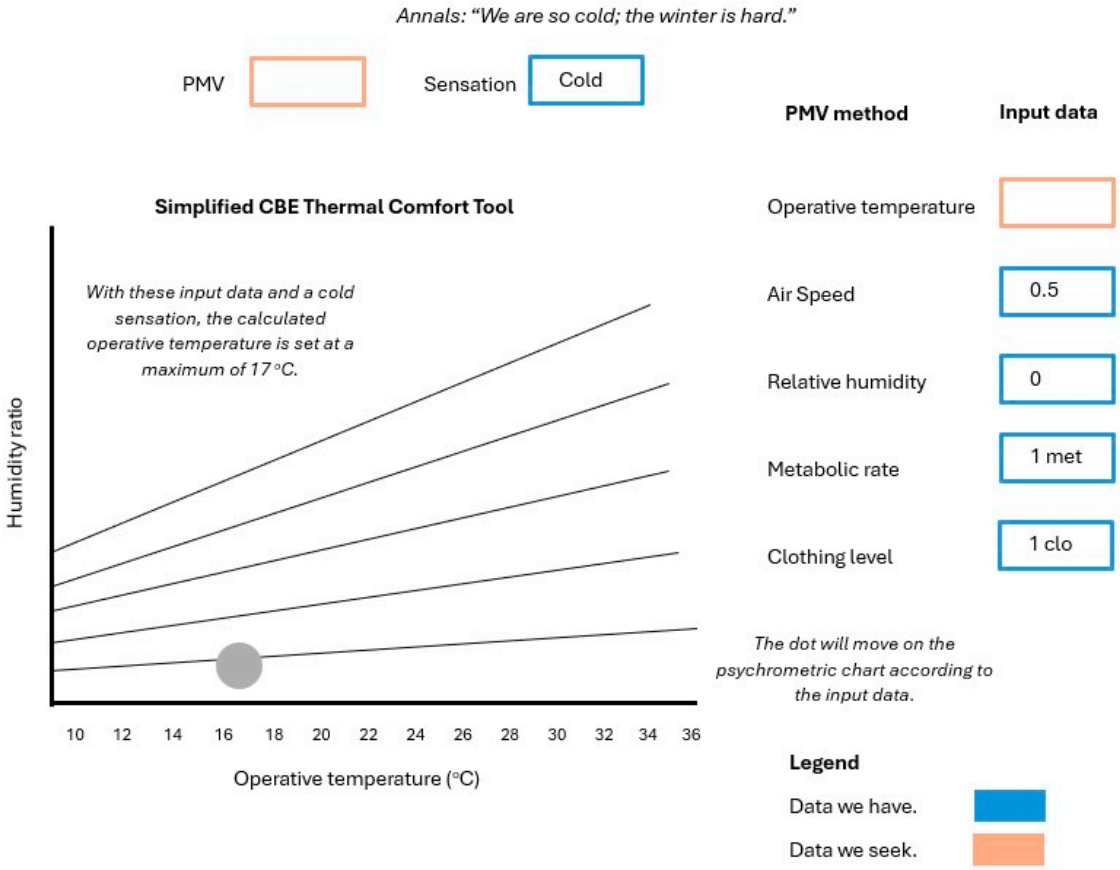


Figure 3. Determining the operative temperature according to the thermal sensation (fictional example).

4. Results

4.1. Case Study

Our research uses the Congregation of the Sisters Adorers of the Precious Blood (*Adoratrices du Précieux-Sang*) as a case study. They are Canada's first contemplative religious congregation, meaning that their spiritual and social action are essentially devoted to prayer and the adoration of Christ. This Congregation settled in Joliette in early 1908 and established its conventual property in this city: the Monastery of the Precious Blood. It is located in the Lanaudière Region on the north shore of the St. Lawrence River (some 40 km northeast of Montreal). Before moving further north, the Adorers were founded in 1861 in St-Hyacinthe, on the south shore of the St. Lawrence River.

The Joliette Monastery, built of grey stones, has undergone several phases of expansion. First, in 1924, a south wing was added to the central part (main body). Then, in 1947, a north wing was added to the complex. Finally, in 1995, a rear annex completed the complex's expansion phases. Over the years, the operational energy sources were diversified: coal (1907–1959), fuel oil (1959–1995), and gas and electricity (1995–2023). In the mid-1970s, the Congregation joined the Order of St. Benedict and adopted the name of Benedictine Nuns, while the building was renamed Abbaye Notre-Dame-la-Paix. Between 2021 and 2023, it was converted into a multi-generational living environment open to both the public and the nuns [90–92].

4.2. Data Identification and Analysis

To draw a parallel with the TSV scale, we have selected three excerpts from the Annals of the Benedictine Nuns. These excerpts, which focus on references to thermal sensation, cover the building's evolution over a 29-year period (1908–1937).

We identified and deconstructed references to thermal sensation according to the four parts of the analysis of documentary sources outlined in the methodology (see Section 3.2):

authenticity (part no. 1), identification of the author(s) (part no. 2), nature of perceptions (personal or collective) (part no. 3), and classification of perceptions (direct or indirect) (part no. 4) (Table 3).

Table 3. Analysis of the documentary sources (the Annals of the Benedictine Nuns).

Excerpts from the Annals (Translation into English)	Authenticity (Part No. 1)	Identification of the Authors (Part No. 2)	Nature of Perceptions (Part No. 3)	Classification of Perceptions (Part No. 4)
"It's cold in the house; the furnace is doing its best, but it doesn't warm up. . ." (2 February 1908). "This morning, Mr. Blondin's workers arrive to install the two new furnaces. [. . .] Our Mother is worried about health issues, especially [the health] of the novices whom she keeps as close as possible to the kitchen fire" (17 February 1908).	Authentic. Found in an official collection of Annals.	Both excerpts were written by the same annalist	Collective	1st excerpt: direct perception 2nd excerpt: indirect perception
"Cold. . . for two days now, we have been fervently holding the procession to Saint Joseph to obtain coal. We only have a few shovelfuls of coal left in the cellar and winter is not over! [. . .] The coal cart ordered last summer still hasn't arrived yet...". (19 February 1923). "After several requests here and there, we finally obtain two tons of coal from the Sisters of the Sacred Hearts of Jesus Mary [. . .]. We turn off one of our furnaces to conserve this small supply, as there is no longer any hope of obtaining more anywhere" (26 February 1923).	Authentic. Found in an official collection of Annals.	Both excerpts were written by the same annalist.	Collective	1st excerpt: direct perception 2nd excerpt: indirect perception
"Our heating appliances work wonders. The chapel provides significant protection against the north" (30 January 1937).	Authentic. Found in an official collection of Annals.	N/A	Collective	Indirect perception

4.3. Gradation of Data According to the TSV

Mention of the thermal sensation fluctuates considerably between the excerpts dated from 1908 and 1923, on the one hand, and those dated from 1937, on the other hand. The first two excerpts clearly fall within the −3 (cold) scale (Tables 4 and 5), while the third excerpt falls within the 0 (comfortable/neutral) scale (Table 6). There are many possible reasons for these variations in thermal sensation: fuel supply difficulties (coal in this case) or deficiencies in the heating system. A cold thermal sensation may also underlie a policy of low energy consumption within the congregation. Indeed, historically, religious communities have often prioritized saving energy and food in order to restrict spending and consumption for survival.

The determination of the TSV based on the annalists' interpretations provides only a temporary depiction of the thermal sensation experienced in the monastery at different times. It needs to be supplemented by a systematic use of sources to establish chronological series during heating periods (beginning of November to end of April each year). In the present case, the archives of the Monastery of the Precious Blood (Annals of the Benedictine Nuns) contain the information required to establish these chronological series.

Table 4. Seven-point scale of the TSV in February 1908.

Seven-Point Scale	Thermal Sensation	Examples—February 1908
−3	Cold	OV—«Il fait froid dans la maison; la fournaise donne ce qu'elle peut, mais ne réchauffe pas. . .» (2 février 1908). TR—"It's cold in the house; the furnace is doing its best, but it doesn't warm up. . ." (2 February 1908).
		OV—«Ce matin, les ouvriers de Monsieur Blondin arrivent pour installer les deux nouvelles fournaises [. . .]. Notre Mère est inquiète des santés, surtout des novices qu'elle fait demeurer le plus près possible du feu de la cuisine» (17 février 1908). TR—"This morning, Mr. Blondin's workers arrive to install the two new furnaces. [. . .] Our Mother is worried about health issues, especially [the health] of the novices whom she keeps as close as possible to the kitchen fire" (17 February 1908).
−2	Cool	
−1	Slightly cool	
0	Neutral/Comfortable	
+1	Slightly warm	
+2	Warm	
+3	Hot	

Table 5. Seven-point scale of the TSV in February 1923.

Seven-Point Scale	Thermal Sensation	Examples—February 1923
−3	Cold	OV—«Froid. . . depuis deux jours nous faisons avec grande ferveur la procession à Saint-Joseph pour obtenir le charbon. Nous n'avons plus que quelques pelletées de charbon dans la cave et l'hiver n'est pas fini! [. . .] Le char de charbon commandé depuis l'été dernier ne nous arrive pas. . .» (19 février 1923). TR—"Cold. . . for two days now, we have been fervently holding the procession to Saint Joseph to obtain coal. We only have a few shovelfuls of coal left in the cellar and winter is not over! [. . .] The coal cart ordered last summer still hasn't arrived yet. . ." (19 February 1923).
		OV—«Après plusieurs demandes ici et là, nous obtenons enfin deux tonnes de charbon des Sœurs des Saints Cœurs de Jésus-Marie [. . .]. Nous éteignons une de nos fournaises pour ménager cette petite provision, car il n'y a plus d'espoir de nous en procurer nulle part.» (26 février 1923). TR—"After several requests here and there, we finally obtain two tons of coal from the Sisters of the Sacred Hearts of Jesus Mary [. . .]. We turn off one of our furnaces to conserve this small supply, as there is no longer any hope of obtaining more anywhere" (26 February 1923).
−2	Cool	
−1	Slightly cool	
0	Neutral/Comfortable	
+1	Slightly warm	
+2	Warm	
+3	Hot	

Table 6. Seven-point scale of TSV in January 1937.

Seven-Point Scale	Thermal Sensation	Examples—January and August 1937
−3	Cold	
−2	Cool	
−1	Slightly cool	
0	Neutral/Comfortable	OV—«Nos appareils de chauffage font merveille. La chapelle protège beaucoup contre le nord» (30 janvier 1937). TR—"Our heating appliances work wonders. The chapel provides significant protection against the north" (30 January 1937).
+1	Slightly warm	
+2	Warm	
+3	Hot	

As mentioned earlier, after collecting the historical TSVs, we used the CBE Thermal Comfort Tool to infer the operative temperatures. To calculate these temperatures, we first gathered additional data other than the thermal sensation as recorded in the Annals. These data included air speed, relative humidity, metabolic rate, and clothing level. We assessed the air speed and the relative humidity based on a scenario that depended on the building's construction materials, the use of the heating system, and the winter season. We estimated the metabolic rate based on the traditional quiet activities of the nuns (e.g., sitting, writing, and reading) and the clothing level based on traditional winter clothing (e.g., boots, long underwear top, and long-sleeved long gown).

We found that, when the nuns were cold (TSV = −3), the associated operative temperature ranged between 0 °C and 17 °C, and when they felt neutral/comfortable (TSV = 0), the related operative temperature was set somewhere between 25 °C and 29 °C (Tables 7 and 8).

Table 7. Inputs used to calculate the predicted mean vote (PMV) for February 1908 and 1923.

PMV Inputs	Detailed PMV Inputs According to CBE Thermal Comfort Tool	Data
Operative temperature (°C)		0–17
Air Speed (m/s)		0.5
Relative humidity (%)		0
Metabolic rate	Activity level: seated, quiet [1]	1 met
Clothing level	Clothing items [2] Women's underwear Knee socks (thick) Boots Long underwear top Long underwear bottom Long-sleeved long gown [3,4]	1 clo

[1] Religious communities were engaged in quiet activities. [2] This choice was inspired by the assessment of the traditional clothing worn by religious communities in Quebec. [3] In the CBE Thermal Comfort Tool, there is no option to add any head coverings. [4] When using the PMV, the clothing insulation value (clo) cannot be higher than 1.5 clo.

It should be noted that the results of the three TSVs established for 1908, 1923, and 1937 are not necessarily consistent with the operational temperatures projected by the predicted mean vote (PMV). Indeed, on the one hand, an operational temperature set at 17 °C remains rather low, while, on the other hand, by virtue of the factors we raised above (possibility of momentary fuel shortages, possibility of heating system deficiencies, and the presence of a strong thrifty spirit), a more realistic operational temperature would be set at a minimum of 18 °C or even 19 °C. Such an operational temperature would have

to be considered as a form of average, given that significant temperature variations could be felt from one room to another in the building (probably warmer in rooms adjoining heating systems).

Table 8. Inputs used to calculate the predicted mean vote (PMV) for January 1937.

PMV Inputs	Detailed PMV Inputs According to CBE Thermal Comfort Tool	Data
Operative temperature (°C)		25–29
Air Speed (m/s)		0.5
Relative humidity (%)		0
Metabolic rate	Activity level: seated, quiet	1 met
Clothing level	Clothing items Women's underwear Knee socks (thick) Boots Long underwear top Long underwear bottom Long-sleeved long gown	1 clo

4.4. Scope, Limitations, and Strengths of the Methodology and Data

To discuss the scope, limitations, and strengths of the methodology and data used in this article, it is imperative to return to our basic objective. The present research aims to qualitatively estimate the past operational energy of a historic religious building. As previously noted, there are very few qualitative approaches for assessing the operational energy of buildings. Most existing methods primarily focus on the thermal comfort through present day questionnaires [60,61,64,67,79,80]. However, this methodology does not enable us to estimate the past thermal comfort experienced by the building's users. It is essential to estimate the past operational energy of historic religious buildings as accurately as possible to provide a more solid foundation for LCA. The qualitative perspective of reconstructing the TSV and its potential to estimate the operational temperature is one of the promising avenues for future research.

However, the methodology we propose has its limitations. For instance, it involves finding many mentions of thermal comfort over time in the Annals. The challenge lies in the irregularity of such references in these archive documents. Thus, the researcher must rely on indirect perceptions of thermal comfort rather than direct perceptions, which have greater evocative power.

It should be noted that, to our knowledge, there is no method for controlling our approach in qualitative research. The available methods primarily allow for the documentation of social representations that counterbalance individual perceptions; however, their objectives are more sociological in nature and do not align with the aims of our study [100]. Nonetheless, our qualitative approach is complementary to the quantitative approaches explored above, which retain all their relevance.

Obviously, the qualitative nature of the sources we use must be acknowledged and accepted from the outset. To reveal their qualitative scope, these sources must be properly situated and understood within the context of a religious community; they are not suited to linear regression or to the sampling logic inherent in quantitative research. These sources must be viewed as carriers of collective voices and perceptions, embedded in the reality of their time and the buildings associated with them.

5. Discussion

This article advocates for the development of qualitative approaches to assess the past operational energy of historic buildings. As our literature review section has shown, the vast majority of studies focusing on operational energy are centered around the quantitative

method of LCA [8,11,12,14,54]. LCA offers several advantages, notably its consideration of embodied and operational energy throughout the entire life cycle of buildings. However, when assessing the past operational energy of a building, LCA is less flexible, as it primarily projects consumption levels based on contemporary referents and habits. It is therefore necessary to gain a better understanding of the past energy consumption of historic buildings.

Our literature review indicates that few authors have attempted a qualitative assessment of past operational energy [43–46]. There is a great deal of complexity in the development of a qualitative and historical method, meaning that it requires sources that are often difficult to identify and collect. Moreover, it demands an understanding of the past that is not anachronistic, meaning not formed from the judgment and values of the present time.

In our article, we have chosen to assess the past operational energy based on thermal comfort. This choice allows us to adopt a qualitative approach, as thermal comfort is predominantly a subjective and qualitative experience based on perceptions.

From the outset, we emphasized that there are many ways to approach thermal comfort. In our case, we focused on the thermal sensation using the TSV. This index has the advantage of being easy to implement and can be adjusted based on individuals' perceptions of their thermal sensation experienced within a historic building. Determining the thermal sensation using the TSV does not provide direct information on operational energy. However, the TSV is fundamentally designed to align with the PMV, which is based on parameters that allow for the estimation of the operational temperature (with the CBE Thermal Comfort Tool).

Previously, we have underlined that there are numerous criticisms of the PMV model, and it must be used with caution [60,61,64,67,78,80]. In this article, we also intended to contribute to the constructive criticism of the PMV by proposing a new method for establishing a TSV using a historical perspective, specifically applied to a historic religious building.

Our case study of the Monastery of the Precious Blood suggests a potential gap between the TSV and the operational temperature projections based on the parameters associated with the PMV, such as the building's context (e.g., air speed and relative humidity) and its monastic lifestyle (e.g., metabolic rate of the nuns and clothing level). From this specific qualitative perspective, our case study aligns with other studies that have noted a discrepancy between the TSV and the PMV [60,61,64,67,80]. In the present case, it is important to note that such a discrepancy primarily reflects the gap between the qualitative perception of the thermal sensation, as expressed by the TSV, and the PMV parameters intended to correspond to the TSV, including the operational temperature.

Research in the archive documents of the Monastery of the Precious Blood in the city of Joliette revealed that it is possible to trace past perceptions of thermal sensation among individuals residing in a monastery and to grade them based on the TSV scale. Our objective was not to compile exhaustive chronological series but rather to develop a methodology that would allow for such series to be considered. Our aim was to address the gaps in the studies that have attempted to qualitatively assess the TSV using questionnaires, which often overlook the past of a historic building.

Despite its limitations, our approach is valuable for gaining a better understanding of the past operational energy of a historic building. The incongruities observed between the TSV and the PMV may prompt a reconsideration of certain PMV parameters, including operational temperature and other essential data for its calculation. This reconsideration can contribute to a more accurate understanding of the actual energy consumption of a building at given times in its history.

It is important to encourage the development of qualitative methods to assess the past operational energy of buildings, particularly historic ones. This aspect is especially significant, as a building's energy consumption is directly linked to its carbon footprint, meaning that, when the former increases, the latter does as well. By using our method, we can gain a more precise understanding of both the energy use in a building and

its environmental impact from a life cycle perspective. This approach will allow for more accurate assessments and comparisons of various scenarios. For instance, from an environmental perspective, is it better to demolish historic buildings and construct new ones with the same functions or to maintain the existing historic structures? The ability to answer these kinds of questions more accurately is crucial for the sustainable conservation of heritage and contributes to the fight against climate change. Scientific research must constantly refine its approaches and methods to better document this aspect.

Our method could be used more broadly. In the province of Quebec alone, there are over 4000 historic religious buildings, many of which belong to religious communities. This religious heritage, despite its carbon footprint, could be sustainable, but we need to study it in all its forms.

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