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Modification of Walls' Thermal Resistance Value in the Saudi Building Code According to a Comprehensive Green Assessment

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Mostadam is the Green Building Rating System in the Kingdom of Saudi Arabia. Indoor thermal comfort assessment is one of the key issues in Mostadam. Controlling the thermal characteristics of the building envelope is one of the main methods to achieve thermal comfort. In Mostadam, these characteristics should comply with the Saudi Building Code for energy conservation, where the required thermal resistance value (R-value) of the above-grade walls for twelve thermal zones are unified despite their various climatic aspects. Taif city, for example, has a moderate temperature for most of the year in contrast to many Saudi cities that share the walls' R-value. The purpose of this paper is to highlight the importance of considering a comprehensive assessment of a building across all its life stages before judging any green practice. Therefore, a simulation methodology was used for a set of models through which the impact of R-value on the building's assessment to its different stages can be checked. Simulation results showed that half the value of the required Saudi code's R-value can give the same thermal target in Taif city. But the higher R-value means more materials and loads, which accordingly leads to more construction costs. To decide that a conservation method is appropriate, it should be judged over the whole life cycle of the building. Thus, it is not considered appropriate if a thermal solution gives the same energy consumption during the operational building stage but more cost during the construction and demolition stages. The manuscript results in that the suitable R-value that should be used within the Saudi codes and, therefore, Mostadam for the above-grade walls in Taif city is 1 (m^2 K)/W, as it maintained the targeted thermal comfort achievement with less building construction cost. It is recommended to evaluate the Saudi code values accordingly.

Keywords: Saudi Building codes, Mostadam, R-value, thermal comfort, predicted mean vote, predicted percentage of dissatisfaction.

Introduction

Green architecture is a highly effective system in harmony with its environment through the self-control of its inputs and outputs, with minimal negative environmental impact and resource consumption over the building's life cycle (Fekry et al., 2014). Several green building rating systems (GBRSs) emerged to ensure the implementation of green architecture. They assist in the issuance of certificates for buildings to show their compliance with the different green issues. Building assessment through the GBRSs is continually developing to ensure the achievement of required issues with maximum credibility. Mostadam is the local GBRS of the Kingdom of Saudi Arabia (KSA). In KSA, the construction industry is the sector that uses the most energy. Saudi Arabian buildings were mostly accredited using the Leadership in Energy and Environmental Design (LEED) rating system developed by the United States Green Building Council. Then Mostadam appeared to be more adapted to the Saudi construction industry and to achieve the Saudi targets of the KSA Vision 2030. Mostadam assesses buildings according to local and international standards. The Saudi Building Codes (SBCs) are one of the major standards used in Mostadam to assess its issues. The Sustainable Building Program developed the Mostadam system as a framework for evaluating overall sustainability to solve the long-term sustainability issues that KSA buildings are experiencing (Hajr et al., 2024; Shamseldin, 2022; KSA-Ministry of Housing et al., 2019; Sirror et al., 2022).

Building codes are of high importance to apply and verify the green requirements in buildings. The Saudi Building Code National Committee established the SBC 601 for energy conservation requirements to create a comprehensive collection of regulations for materials, environmental conditions, and prevalent construction techniques in the Kingdom. These requirements provide minimum prescriptive and performance-related regulations to the maximum extent possible benefits (Saudi Building Code National Committee, 2018; The Saudi Building Code National Committee, 2022). After releasing local codes, several practices using these codes help to improve their contents toward a greener level (Shamseldin, 2015). These modifications are healthy if they help greener buildings achieve. For example, Xie et al. (2023) evaluated the United States' energy code compliance to assess its efficiency and overcome the gap between the actual energy savings and the energy standards imposed by the code. They discussed an adjustment for the used ways and metrics to evaluate energy code compliance (Xie et al., 2023). Fereidani et al. (2023) have evaluated the efficacy of the energy levels specified in the Iranian building code in reducing energy consumption under current and future climate conditions. They discussed an adjustment for the code to mitigate global warming (Fereidani et al., 2023). Hussein et al. (2022) have worked on enhancing the Building Energy Efficiency Code in Palestine by adjusting the different U-values for the building envelopes for the different climatic zones; to improve their thermal performance (Hussein et al., 2022).

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is one of the most famous international standards to assess green buildings. It is used in Mostadam in several issues, especially related to energy consumption. Appendix G in this standard helps the assessment of the energy performance and sets the thermal characteristics values of buildings to be used according to the assessed building climatic zone. Nevertheless, local codes can have priority over ASHRAE (ASHRAE Standards Committee, 2022). Shamseldin (2022) has discussed the SBC versus ASHRAE in assessing the Energy Performance item in the Mostadam commercial version. The SBC envelope values helped the achievement of the required energy conservation as required in Mostadam, and thus can compete with ASHRAE in Mostadam regarding that issue (Shamseldin, 2022).

Indoor thermal comfort is always a main issue in all GBRSs to be achieved. When focusing on the thermal comfort assessment field in Mostadam, the used envelope thermal characteristics values in the SBC – that Mostadam mainly uses regarding that issue – are under attention. Thermal conductivity is the time rate of the heat flow through a body from one of its bounding surfaces to the other. The thermal transmittance coefficient (U) is the heat transmission from air to air. The thermal resistance (R) is the thermal conductance reciprocal. The overall thermal resistance of the exterior building envelope (roof, opaque wall, floor, window, skylight, etc.) includes the area-weighted R-values of the specific component assemblies (such as air film, insulation, drywall, framing, glazing, etc.) (Saudi Building Code National Committee, 2018). The manuscript discusses whether the SBC used R-values for the above-grade walls are appropriate from the whole green building's side of view or not. The discussion was regarding whether the R-value could achieve the required thermal target through the operational building stage on the same lane of other building stages' priority or not. This concept appeared after noting that twelve climatic zones in KSA have the same required thermal values for their above-grade walls R-value. One of these climatic zones includes Taif city, which has a moderate temperature almost all year around. On the other hand, cities such as Jeddah, which is known for its harsh summer, have the same value (Shamseldin, 2023a).

Building life cycle is related to the green architecture definition. It consists of three main stages, which are the construction, operation, and demolition stages. These stages are strongly related to each other, so any impact on any stage affects the others (Fekry et al., 2014; Shamseldin, 2016; Shamseldin, 2018). Green assessment should be studied as a holistic system. Any green assessment that only spots a certain building stage without noting its effect on the other stages cannot be accepted (Shamseldin, 2018).

The research paper discusses the comprehensive suitability of the SBC R-value used in evaluating the thermal performance of buildings in Saudi Arabia, specifically in Taif city. The research paper studied the effect of the thermal characteristics found in the current Saudi code on the building's performance in Taif city. According to the results, the R-value of the external building envelope as set in SBC achieves the thermal comfort performance required by Mostadam. However, it was found that the thermal comfort target in Taif city can be achieved with an R-value that is half less than set in SBC. Because the building environmental evaluation must be comprehensive for all stages of the building's life cycle, modifying the R-value in the simulated models in Taif city reduced the costs of building construction without affecting the required thermal comfort achievement. Thus, the paper suggests modifying the determined R-value in the SBC for the external walls of Taif city buildings to achieve a greener practice. The envelope characteristics values of the SBC should also benefit from related feedback.

Methodology

A simulation method was used to get the required inputs to the thermal comfort indices calculations. The used simulation software is the DesignBuilder which complies with Mostadam and most other GBRSs Shamseldin et al. (2020). Several models were simulated according to Taif's weather file. These models are A, B, C, and D. The difference between these models is the window-to-wall ratio (WWR) which has different thermal characteristics in the SBC. Case 1 of all models was simulated totally according to SBC values. Cases 2 and 3 of all models were simulated as Case 1 after changing the above-wall R-values. The main simulation results were the thermal comfort values such as the average of the operational temperature and the relative humidity among different seasons. The previous results were used within a thermal online tool to obtain the thermal indices results. This tool is the Center for the Built Environment (CBE) tool that relies on the ASHRAE-55 standard. The DesignBuilder software is also used to get the total cost of constructing the different models' cases to compare them together and determine the related reduction of cost. The research paper identified the possibility of reducing the R-value and achieving the required thermal comfort as well, and in return, reducing the cost of construction. An analytical method is used in the discussion and the findings, and allows reaching the conclusion and recommendations.

Indoor thermal comfort indices

Thermal comfort is assessed by several methods. One of the recent methods is ensuring that some thermal indices are in the acceptable range. These indices include the predicted mean vote (PMV), which is an index that estimates the mean value on the seven-point thermal sensation scale given by the votes of a significant number of people. The second index is the predicted percentage of dissatisfaction (PPD), which is an indicator that gives a quantifiable prediction of the number of persons who are thermally displeased based on PMV (ASHRAE, 2010; Ekici, 2013). The PMV model is a well-known thermal comfort model that is used globally to determine the thermal comfort conditions in buildings. The application of Fanger's heat balance equation is used for the computation of PMV to assess the level of thermal comfort. It is detailed in the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) Standard 55-2004 (Gilani et al., 2015; Dyvia and Arif, 2021).

Criticism of the thermal comfort assessment in Mostadam based on SBC

The Ministry of Housing in the Kingdom of Saudi Arabia has created the Mostadam system which is managed by the Sustainable Building entity. This building rating system was developed to consider the environmental and climatic conditions of KSA and promote the Saudi economy. Mostadam has two main versions up to date, the residential and the commercial versions. In the commercial buildings design and construction manual, there are nine assessment categories, one of which is the Health and Comfort category. The second assessment item under the Health and Comfort category is the Indoor Thermal Comfort. One of the three requirements for the Indoor Thermal Comfort assessment item is to ensure that the PMV and PPD are within accepted ranges. This requirement has one credit point to be obtained when achieved. It states that in compliance with the International Organization for Standardization ISO 7730:2005, thermal modeling is used to assess the comfort levels in the building using the PMV and PPD Methods. To check the PMV and PPD ranges, a simulation could be applied to get the required inputs of the two thermal indices. The PMV and PPD limits according to ISO 7730:2005 either for the design stage or construction stage evidence is that PPD < 10 and that −0.5 < PMV < +0.5, which is also presented in The American National Standards Institute (ANSI) / ASHRAE 55-2010. The thermal model should be during regular hours of operation for 98% of the year (KSA-Ministry of Housing et al., 2019,ASHRAE Standards Committee, 2022). *Table 1* presents the accepted values in Mostadam for these two thermal indices.

Table 1. *Thermal comfort acceptable indices values according to Mostadam (ASHRAE, 2010; KSA-Ministry of Housing et al., 2019)*

PMV range	PPD
−0.5 < PMV < +0.5	<10

To calculate the thermal indices of a space, several thermal inputs should first be found, such as its internal operative temperature and relative humidity. These thermal values depend on spatial and time variables and could be obtained by the simulation process. The simulation includes the building envelope characteristics that surely affect the performance toward thermal comfort. For Mostadam, these characteristics were set in the SBC 601 for energy conservation, which is determined according to certain thermal regions. These regions were divided according to the degree days DD values (base 18°C) from the Meteorology and Environmental Protection Administration. For example, the DD of Riyadh city is 3800°C, Jeddah city is 3900°C, and Taif city is 2200°C. The thermal zones have a range between the annual cooling degree days (CDD) and the Annual heating degree days (HDD). These values represent the sum of annual degree days that have a difference in temperature between the mean temperature for a day and 18°C, either more than 18°C for the cooling or less than 18°C for the heating (Saudi Building Code National Committee, 2018; Shamseldin, 2022). The envelope characteristics that are related to the thermal zones include the above-grade walls R-value besides other characteristics, such as the windows and glass doors U-values and the roof R-value.

It was noticed in the SBC that the R-value cavity for all masonry types of the above-grade walls with wood framing is unified for all Saudi regions that have a DD starting from 1944°C until reaching 4166°C. That means it is unified into 12 climatic zones with extreme differences. It is also unified among the same region for the different openings area that starts from window-to-wall ratio (WWR) less than 10% until more than 50%. This unification affects the logical advantages gained from the given values, but not their reliability of energy conservation. The R-value was set in SBC 601 to 1.937 (m^2 K)/W for the different mentioned regions and different glazed areas, which is a high value that guarantees the achievement of energy conservation for cooling systems, for example. On the other hand, the related energy and cost of the other building stages – such as the construction stage – should also be included to agree on the gained pros. Focusing only on the operational stage of a building cannot be considered a green practice. It could be approved when the energy consumption of the whole life cycle of the building is less than before with no effect on the environment (Saudi Building Code National Committee, 2018).

According to SBC, Mostadam uses the SBC thermal values only if the WWR is less than 50%, and after that, ASHRAE 90.1 values should be used according to the climatic region it belongs to. Taif city belongs to the 2B climatic zone in ASHRAE 90.1 standards. Although the roof R-value in ASHRAE is reasonable compared to those used in SBC, the R-value for the above-grade wall is far less from those in SBC ((0.704 (m^2 K)/W [U-0.124 Btu/h ft^2 °F]) despite the logical need to be increased with the WWR increases (Saudi Building Code National Committee, 2018; ASHRAE, 2019; ASHRAE Standards Committee, 2022). This point will be discussed within the discussion section to show if the ASHRAE values are proper to be used or not.

Simulation models

An office space with an area of 10 x 10 m^2 was chosen to present a commercial building space. This space was built in the DesignBuilder simulation program for Taif city using its weather file. The weather file helps include the annual weather stream for the city's specific climate zone by daily observations of temperature, humidity, wind, solar radiation, and precipitation over a 30-year duration. Cases A, B, C, and D present the different WWR options shown in the SBC. Case A presents WWR 10% or less, Case B presents WWR more than 10% and not more than 25%, Case C presents WWR more than 25% and not more than 40%, and Case D presents WWR more than 40% and not more than 50%. The study did not include spaces of WWR of more than 50%, because the manuscript focuses on the values of SBC, while any case that uses WWR more than this value should use the values of ASHRAE/IESNA 90.1 as previously mentioned (ASHRAE Standards Committee, 2022; Shamseldin, 2023b). *Table 2* shows the codes of the different models (A, B, C, and D) to be easily presented in the following sections.

For each previous model, three cases were built in the simulation program with different Above-grade walls R-values. Case 1 in all the models represents the thermal characteristics of the SBC 601 for energy conservation requirements. Noting that Taif city belongs to the thermal zone that ranges within 1944 ≤ HDD / CDD (°C) < 2222, the SBC tables that are related to this region range were thus used. *Table 3* shows the Case 1 characteristics for all the models. The chosen

Table 2. *The coding of the simulated models according to the model WWR*

Model code	WWR			
	10% [presents the 10 % or less]	25% [presents > 10 % ≤ 25%]	40% [presents > 25 % ≤ 40%]	50% [presents > 40 % ≤ 50%]
				
A	●			
B		●		
C			●	
D				●

Table 3. *Case 1 thermal characteristics of all models (A, B, C, and D) based on SBC 601 requirements (Saudi Building Code National Committee, 2018)*

Model - case	R-value of roof (m^2 K)/W	R-value cavity of above-grade walls (m^2 K)/W	Windows and glass doors	
			U-value W/ (m^2 K)	SHGC
A – 1	2.465	1.937	Any	Any
B – 1	3.346	1.937	3.975	0.5
C – 1	3.346	1.937	2.839	0.4
D – 1	3.346	1.937	2.839	0.3

simulated materials were the most common in Saudi construction practices, the roof was chosen always to be a concrete slab with continuous insulation, and the above-grade walls were masonry with wood framing. The envelope has no shadings or louvers; thus, the projection factor (PF) is zero for the windows and glass doors. The solar heat gain coefficient (SHGC) determines how much solar radiation enters the room through the window, which is a ratio that equals 1 when the maximum amount of solar heat is allowed by a window, and 0 for the least amount. The SHGC in the SBC is determined beside the glass U-values (Saudi Building Code National Committee, 2018).

The three simulated cases for each model had the same basic characteristics as in Case 1 (SBC 601 requirements) of these models except for changing the above-grade walls R-values. Case 2 of all models used an R-value of 1 (m^2 K)/W. Case 3 used an R-value of 0.85 (m^2 K)/W. *Table 4* presents the R-value used for Cases 1 to 3 and the simulated wall layers to achieve them.

As mentioned, all models had the same characteristics except for the wall's R-value. *Table 5* shows the roof layers according to their required SBC 601 R-value that are unified for the same model. *Table 6* also shows the type of glass used for the different models according to their thermal characteristics that are unified for the same model too.

Fig. 1 and *Fig. 2* show the concept of the simulated models, where all models share the wall R-values for the same cases, and all cases share the same WWR and comply with the Saudi Building codes for the same model.

Table 4. *The wall layers for the simulated models according to the proposed R-values for the three cases of each mode* (Shamseldin, 2023b)

Construction element	Model – case	R-value (m^2 K)/ W	Layers from the outermost to the innermost to achieve the R-value
wall	All – case 1	1.937	Plastering 2.5 cm, brick 12 cm, expanded polystyrene 6 cm, brick 12 cm, and plastering 2.5 cm
	All – case 2	1	Plastering 2.5 cm, brick 12 cm, expanded Polystyrene 2 cm, brick 12 cm, and plastering 2.5 cm
	All – case 3	0.85	Plastering 2.5 cm, brick 40 cm, and plastering 2.5 cm

Table 5. *Roof layers for the simulated models according to the thermal requirements in the SBC 601* (Shamseldin, 2023b)

Construction element	Model – Case	R-value (m^2 K)/ W	Layers from the outermost to the innermost to achieve the R-value
roof	A – All	2.465	Roof tiles 2 cm, mortar 2 cm, extruded polystyrene 6 cm, concrete slab 15 cm, and plastering 2 cm
	B, C and D – All	3.346	Roof tiles 2 cm, mortar 2 cm, extruded polystyrene 9 cm, concrete slab 15 cm, and plastering 2 cm

Table 6. *Fenestration types for the simulated models according to the thermal requirements in the SBC 601* (Shamseldin, 2023b)

Fenestration element	Model – Case	U-value W/(m^2·K)	SHGC	Glass type to achieve the required U-value and SHGC
Windows and glass doors	A – All	Any (6.121)	Any (0.58)	Single blue glass 0.6 cm (U = 6.121 W/(m^2 K) – SHGC = 0.58)
	B – All	3.975	0.5	Double-glazed two clear 0.3 cm panes and 0.6 cm air in between
	C – All	2.839	0.4	Double-glazed two gray 1.2 cm panes and 1.3 cm air in between
	D – All	2.839	0.3	Double glazed two gray 1.2 cm panes and 1.3 cm argon

Fig. 1. *Left to right: Cases 3 of Model A, B, C, and D where the walls layers and thus its R-value are unified while other characteristics comply with SBC 601*

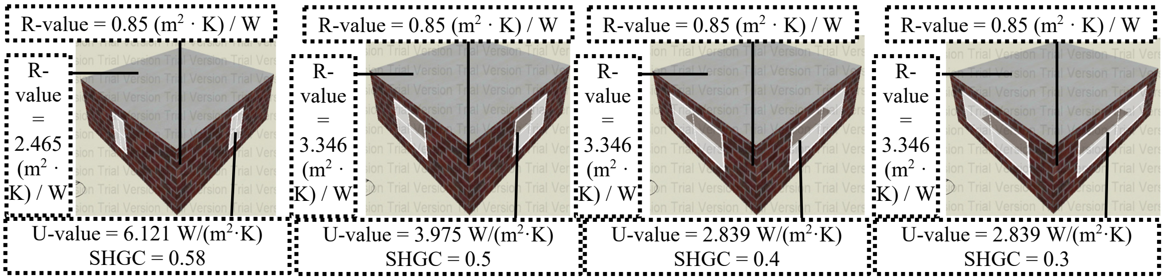
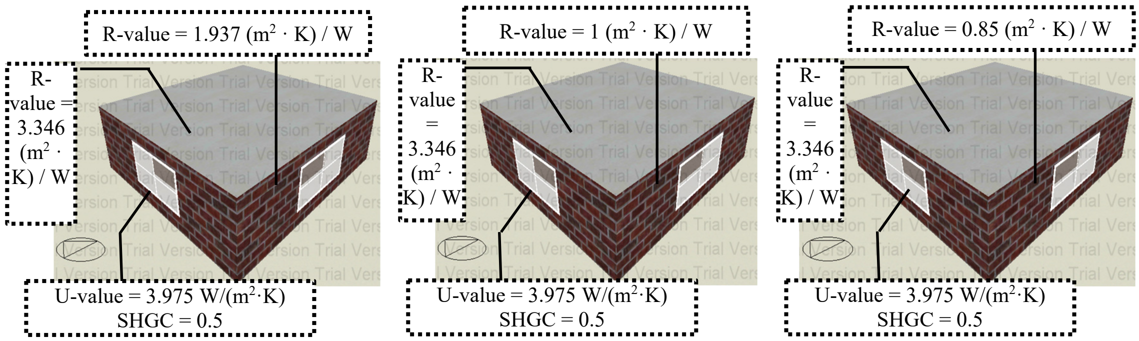


Fig. 2. *Left to right: Cases 1, 2, and 3 of Model B (WWR = 25%) where only the wall's R-values are different, while other characteristics comply with SBC 601*



Thermal Results of Models

Case 3 in all models gave results that failed to achieve the thermal comfort indices in the internal spaces. While Case 2 presented a successful thermal case for all models according to PMV and PPD indices despite it having lower wall R-value of SBC 601. Case 1 also succeeded but with a wall R-value that is approximately double the Case 2 wall R-value to comply to SBC 601. *Table 7* shows the different thermal simulation results for the different models and their cases, and the related comfort achievement results. The main thermal simulation results from the DesignBuilder software were the average of the operative temperature (°C) and the average of the relative humidity (%) for each season. The simulation results were according to the four main thermal seasons: summer (June, July, and August), autumn (September, October, and November), winter (December, January, and February), and spring (March, April, and May). The PMV and PPD achievement results were also according to the four seasons. The calculations to obtain the PMV and PPD indices also needed some inputs such as the metabolic rate, the clothing level, and the air speed. The metabolic rate was set as 1 met for reading and seating activities. The clothing level was set as 0.5 Clo in summer, 0.61 Clo in autumn and spring, and 1 Clo in winter according to the typical indoor clothing for these seasons (Shamseldin, 2023b; Center for the Built Environment (CBE), n.d.; Dyvia and Arif, 2021). The airspeed was set as 0.2 m/s with local control as advised in ASHRAE/ISO standards as a maximum airspeed velocity without adjustment. Note that Taif city has an airspeed that could reach 4 m/s if not controlled (American Society of Heating Refrigerating and Air-Conditioning Engineers Standards Committee, 2010;Center for the Built Environment (CBE), n.d.; Shamseldin, 2023a). The

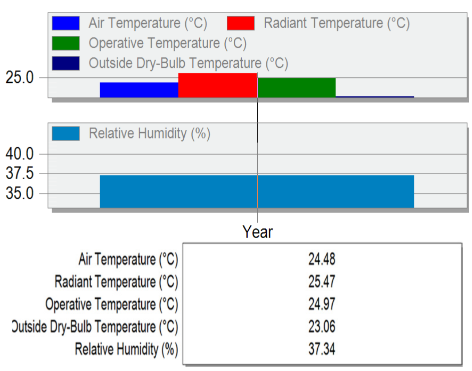
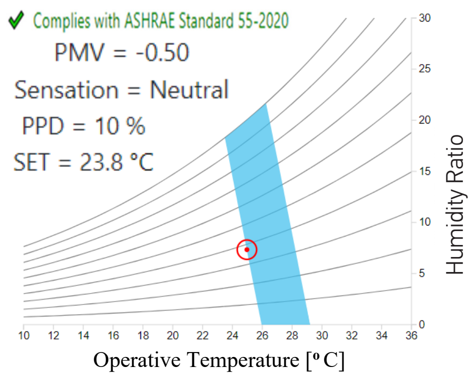
PMV and PPD results were obtained from an online software which is the Center of the Built Environment (CBE) Thermal Comfort tool per ASHRAE-55(Center for the Built Environment (CBE), n.d.).

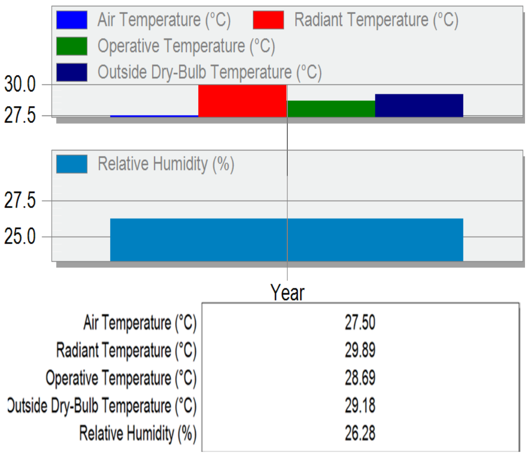
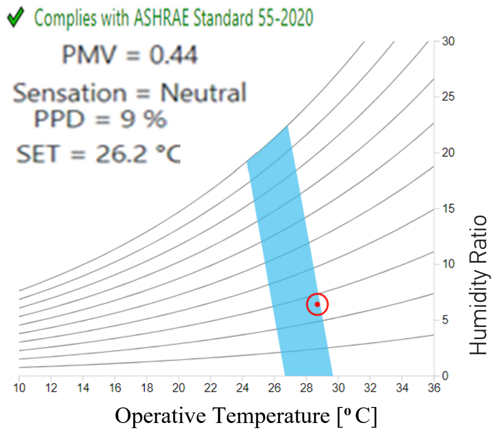
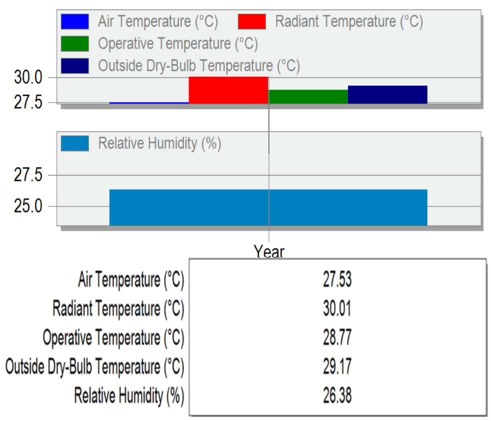
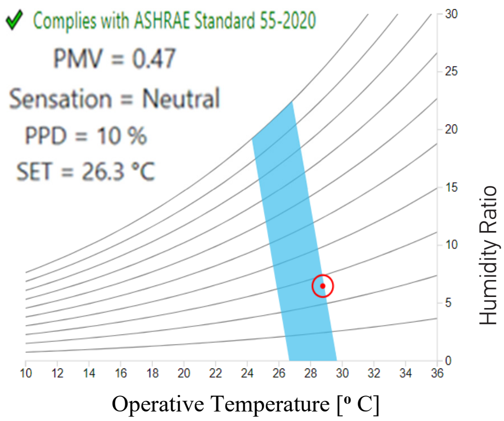
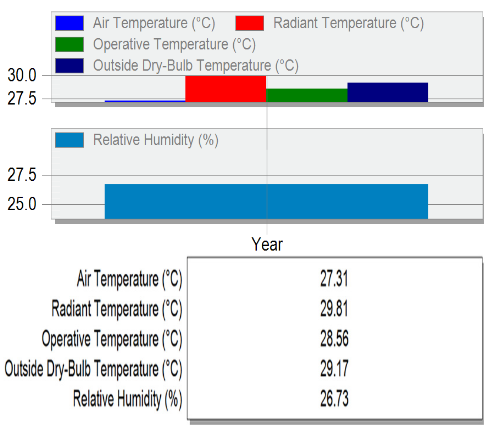
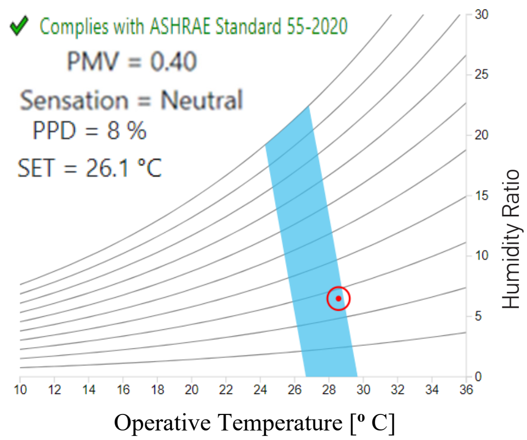
As previously mentioned, Case 2 of all models succeeded in complying with Mostadam requirements while their walls R-value is less than used in Case 1, which presents the compliance of thermal SBC 601 characteristics. *Table 8* shows the obtained results from the simulation program and online tool for Case 2 of all models at the season that seemed to have a thermal problem. The seasons that seemed to have a problem can be recognized from the thermal results of Case 3 in *Table 7*, which are winter and spring seasons for the A model (one season was enough in the Table) and the summer season for the rest models.

Table 7. *Simulation results and related PMV and PPD indices results for the four seasons: summer (Su), autumn (A), winter (W), and spring (Sp) showing their compliance with Mostadam thermal requirements (KSA-Ministry of Housing et al., 2019; Shamseldin, 2023b; Center for the Built Environment (CBE), n.d.)*

Model – Case	Walls R-value ($m^2 \cdot K$)/W	Average of operative temperature (°C) [DesignBuilder software]				Average of relative humidity (%) DesignBuilder software]				PMV [CBE Thermal Comfort Tool]				PPD (%) [CBE Thermal Comfort Tool]				Compliance with Mostadam
		Su	A	W	Sp.	Su	A	W	Sp.	Su	A	W	Sp.	Su	A	W	Sp.	
A – 1	1.937	27.50	25.92	22.89	25.09	27.61	36.40	40.74	37.21	0.23	–0.20	–0.34	0.46	6	6	7	9	√
A – 2	1	27.67	25.88	22.45	24.97	27.30	36.49	41.58	37.34	0.09	–0.21	–0.45	–0.50	5	6	9	10	√
A – 3	0.85	27.63	25.78	22.15	24.77	27.47	36.68	42.19	37.67	0.08	–0.24	–0.53	–0.56	5	6	11	12	X
B – 1	1.937	28.13	27.16	24.02	26.23	26.90	34.88	39.04	35.66	0.25	0.19	–0.06	–0.10	6	6	5	5	√
B – 2	1	28.69	27.44	24.58	26.64	26.28	34.48	38.10	35.06	0.44	0.28	0.08	0.02	9	7	5	5	√
B – 3	0.85	28.93	27.50	24.77	26.74	26.12	34.38	37.77	34.90	0.52	0.30	0.12	0.06	11	7	5	5	X
C – 1	1.937	28.20	26.53	23.36	25.57	26.38	35.93	40.24	36.81	0.28	0.00	–0.23	–0.31	7	5	6	7	√
C – 2	1	28.77	26.74	23.50	25.49	26.95	36.05	40.83	36.88	0.47	0.07	–0.19	–0.33	10	5	6	7	√
C – 3	0.85	28.90	26.77	23.57	25.49	26.70	36.15	41.70	37.25	0.52	0.08	–0.16	–0.33	11	5	6	7	X
D – 1	1.937	28.53	26.80	23.55	25.85	26.62	35.72	40.07	36.50	0.39	0.08	–0.18	–0.22	8	5	6	6	√
D – 2	1	28.56	26.74	23.28	25.71	26.73	35.84	40.59	36.73	0.40	0.06	–0.24	–0.26	8	5	6	6	√
D – 3	0.85	28.88	26.29	22.33	25.15	26.82	37.06	42.89	38.16	0.51	–0.07	–0.47	–0.43	10	5	10	9	X

Table 8. *DesignBuilder Simulation software and the CBE thermal tool results for Case 2 of all models for the critical season that may have a problem in compliance with Mostadam requirements (Shamseldin, 2023b; Center for the Built Environment (CBE), n.d)*

Model -case / critical season	Thermal simulation software results [DesignBuilder Software]	Thermal comfort tool results for PMV and PPD indices [CBE Thermal Comfort Tool]
A – 2 / Sp.		

Model -case / critical season	Thermal simulation software results [DesignBuilder Software]	Thermal comfort tool results for PMV and PPD indices [CBE Thermal Comfort Tool]
B – 2 / Su.		
C – 2 / Su.		
D – 2 / Su.		

Financial Results of Models

The total costs of the built models were obtained from the DesignBuilder simulation program. It is calculated in the British pound sterling (GBP). These costs helped to predict the cost reduction after changing the envelope layers for the different R-values (Shamseldin, 2023b). *Table 9* shows the cost of the different succeeded cases deferred due to their different wall layers. This reduction is due to the less used materials and less deadload on the construction elements. The estimated building construction cost data in the program is based on the costs database for the used service, sub-structure, frame construction per gross internal floor area, the constructions and glazing per surface area, and surface finish per area.

Table 9. *Cost reduction when comparing cases 1 and 2 for all simulated models (Shamseldin, 2023b)*

Model	Total Cost of the building (GBP) [DesignBuilder software]		% of cost reduction
	Case 1	Case 2	
A	131 339	130 724	1.00
B	130 385	129 778	1.00
C	129 431	128 831	1.00
D	129 892	129 288	1.00

Discussion

With the help of simulated models, the results showed that although the SBC thermal requirements led to the targeted thermal comfort in Mostadam, the related cost had the potential to be less. If changing the SBC thermal values could help lower costs with the same targeted thermal comfort, the change is recommended. The SBC thermal requirements for Taif city for a commercial space can easily succeed according to the Mostadam indoor thermal comfort option. But also using an R-value that is nearly half of required in SBC for the above-grade walls led to achieving the thermal comfort range in Mostadam for all WWR probabilities. The cost reduction from changing the walls' R-values to their half value was 1% for all models. This cost reduction can also be translated to construction and demolition energy because of using more materials or removing them. Noting that using or removing any more materials is not only related to the industrial energy of materials, but also affects the transportation, labor, and equipment energy that are related (Shamseldin, 2018).

The whole building life cycle including the construction, operation, and demolition stages is all affected by changing the R-value of any architectural element. So, for the thermal zone with DD between 1944°C and 2222°C where Taif city belongs, and according to the whole building life-cycle criteria, the above-grade walls with wood frame can be changed in the SBC from R-value = 1.937 (m^2 K)/W to R-value = 1 (m^2 K)/W and still achieve the required indoor thermal comfort range as set in Mostadam. At the same time, this change helps the building to benefit from the construction and demolition stages with less cost and needed energy. On the other hand, the required R-value of walls according to ASHRAE 90.1 for the zone that Taif belongs to in ASHRAE is lower than 0.85 (m^2 K)/W, which failed in achieving the required indoor thermal comfort range set in Mostadam without the help of other thermal solutions. So, it is recommended to lower the required R-value for the above-grade walls in the SBC and raise it in ASHRAE to 1 (m^2 K)/W for the thermal zones where Taif belongs to for both references.

Conclusion

According to Mostadam, achieving the PMV and PPD thermal indices within acceptable ranges corresponds to getting a point for the indoor thermal comfort assessment item. The SBC is the local code that Mostadam depends on regarding that issue. According to SBC 601 for energy conservation, Taif city requires an R-value for the above-grade walls with wood frames that are the same as several thermal regions with wide different climatic aspects. Twelve thermal regions have the same R-value including Taif city. Taif city in KSA is considered a moderate climatic city; thus, it was questionable to have a similar thermal requirement as other KSA cities that are known for their harsh hot climates. Using the DesignBuilder software, simulation models were simulated for the different WWR options presented in SBC. Then, three cases for each model were simulated. Case 1 for all models used the R-value for the above grade walls as set in the SBC 601, which is R-value = 1.937(m^2 K)/W, Case 2 for all models used R-value = 1 (m^2 K)/W, while Case 3 for all models used R-value = 0.85 (m^2 K)/W. Case 1 as expected succeeded in achieving the required thermal indices according to Mostadam. Case 2 for all models also succeeded in achieving the required thermal indices although they used nearly half the R-value required in the SBC. Case 3 failed for all models. In addition, the reduction of materials and loads for using less R-value in Case 2 than in Case 1 resulted in a total construction cost reduction of 1% according to the simulation results. The lower cost of materials indicates less energy in the construction and demolition building stages. According to a holistic look at the building life-cycle benefits, the lesser cost and material amount are better if they lead to the required thermal comfort range at the operational building stage. Thus, Case 2 has priority over Case 1 after a comprehensive green assessment. Therefore, it is recommended to change the R-value of the above-grade walls with wood frames for all different WWR in SBC 601 for the thermal zone between 1944°C and 2222°C (where Taif city belongs) to 1 (m^2 K)/W. And it is recommended to justify the SBC requirements to be more suitable for the different climatic zones in KSA and put all building stages into consideration when accepting a code requirement.

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