Buildings **2013**, *3*, 674-688; doi:10.3390/buildings3040674

OPEN ACCESS

buildings

ISSN 2075-5309

www.mdpi.com/journal/buildings/

Article

Performance Evaluation of Modern Building Thermal Envelope Designs in the Semi-Arid Continental Climate of Tehran

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Received: 21 August 2013; in revised form: 27 September 2013 / Accepted: 29 September 2013 / Published: 4 October 2013

Abstract: In this paper we evaluate the thermal performance of a range of modern wall constructions used in the residential buildings of Tehran in order to find the most appropriate alternative to the traditional un-fired clay and brick materials, which are increasingly being replaced in favor of more slender wall constructions employing hollow clay, autoclaved aerated concrete or light expanded clay aggregate blocks. The importance of improving the building envelope through estimating the potential for energy saving due to the application of the most energy-efficient wall type is presented and the wall constructions currently erected in Tehran are introduced along with their dynamic and steady-state thermal properties. The application of a dynamic simulation tool is explained and the output of the thermal simulation model is compared with the dynamic thermal properties of the wall constructions to assess their performance in summer and in winter. Finally, the best and worst wall type in terms of their cyclic thermal performance and their ability to moderate outdoor conditions is identified through comparison of the predicted indoor temperature and a target comfort temperature.

Keywords: dynamic simulation; building energy performance; admittance; occupant thermal comfort

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1. Introduction

In common with many other regions of the world, buildings in Iran account for approximately 36% of the energy consumption of the country [1], with the residential sector responsible for around 33% of total electricity consumption in the country [2]. The building envelope is the main interface between indoors and outdoors and has a significant role in moderating variations in the outdoor weather conditions, providing thermal comfort for occupants and consequently determining the heating/cooling loads of the building. In 2011, the 15–34 year age group accounted for 41% of the total population of Iran [3], which coupled with increasing migration to the cities has resulted in significant demand for new dwellings in the major cities of the country; a situation that appears to be replicated across the world. According to the Building and Housing Research Center [4] construction of 1.5 million residential units is required and statistics indicate an 18% increase in the construction of domestic buildings between March and October 2011 [5]. Energy consumption in the Iranian building sector is more than double the global average [6] and measures to reduce space heating and cooling energy use through intelligent modification of the building envelope materials should be promoted if the country is to play a part in mitigating the global problem of climate change and diminishing fossil fuel resources. The Iranian Ministry of Housing and Urbanism has introduced Code No. 19 [7], which requires the calculation of the whole building heat loss coefficient (W/K) using the steady-state thermal performance of the building envelope, *i.e.*, *U*-value, plus additional losses for thermal bridges. The code requires that the calculated whole building heat loss is less than the equivalent building constructed to *U*-values compliant with the Code [8]. In the vernacular architecture of this warm dry region of Iran, walls employing a high level of thermal mass and the use of local natural materials provide correspondingly high rates of thermal and moisture buffering effects and have delivered associated benefits in terms of thermal comfort for their occupants through the centuries. Common wall types combine a mixture of clay, mud, and straw or brick and are of the order of 50–60 cm thick. Today these materials have increasingly been superseded by predominantly lightweight materials such as hollow clay blocks, Light Expanded Clay Aggregate (LECA) and Autoclaved Aerated Concrete (AAC) blocks, with lower density and reduced thermal storage capacity. To improve thermal performance, some of these lightweight blocks are combined with insulating materials and form much more slender alternatives to the traditional wall constructions.

Thermal simulation software tools have been widely used by architects and engineers for many years and permit investigation and evaluation of various design alternatives influencing, for example, fabric performance and fenestration levels under varying casual gains and climatic conditions *etc*. Such tools provide insight to the dynamic behavior of whole buildings and enable building designers to estimate and optimize envelope thermal performance, occupant thermal comfort and, ultimately, the energy performance of the finished building. Crawley *et al*. [9] provide a thorough appraisal contrasting the capabilities of all the leading simulation tools. This study uses the Integrated Environmental Solutions Virtual Environment (IES-ve) dynamic thermal simulation package, which has been widely validated and its calculation methodology meets the requirements of a number of national and international standards such as the UK National Calculation Methodology (NCM) [10], ASHRAE 55 [11] and ISO 7730 [12]. The IES-ve software was used to model the dynamic thermal performance of a typical apartment building located in Tehran and simulated using hourly weather data over a complete year. The building was simulated for a range of different conventional wall construction systems and the resulting internal temperatures were compared using a simple comfort temperature criterion as presented by Heidari [13]. The results highlight that, whilst the national building regulation (Code No. 19) [7] and related guidelines focus on steady-state (*U*-value) performance and the application of insulation in wall construction to improve its thermal performance, the effect of thermal mass and cyclic behavior of materials in the overall thermal performance of buildings should not be neglected in thermal performance calculations.

2. Envelope Thermal Properties

The value derived from the steady-state calculations (*U*-value) is not an appropriate indicator of the thermal performance of building elements by itself; as it is possible for two walls with the same *U*-value to absorb and release heat at different rates [14]. Steady-state analysis is concerned only with the thermal conductivity of the material; the influence of heat capacity is ignored. Intermittent occupancy and associated heating or cooling operation combined with external diurnal variations mean that the building is more often in a state of flux and, particularly in hot summer conditions, the dynamic behavior of the whole building should be assessed in order to optimize the selection of envelope materials for greatest combined thermal comfort and energy performance. The material bulk properties of heat capacity (C), density (ρ), and thermal conductivity (λ) play an important role in the cyclic performance of the construction, which is significant when the outdoor temperature is cycling below and above the desired indoor temperature. Materials with beneficial thermal properties are either insulating materials, or materials with thermal mass [15] and the effect of thermal mass and thermal insulation which are representatives of dynamic and steady state thermo-physical properties of materials must be taken into account simultaneously [14].

2.1. The Role of Thermal Mass

High thermal mass materials can store more heat compared to other materials when exposed to a source of heat [16]. They also release their heat content more slowly when the source of heat is removed [16]. In winter days high thermal mass materials can store heat energy from incident solar radiation and then will release this heat into the indoor space later in the evening when the passive heat source is removed and more heat is demanded internally, thus reducing the mechanical heating load of the space [16]. In summer time, thermal mass sinks the heat caused by solar radiation in the internal space, preventing sudden peaks in indoor temperature and increased load on air-conditioning units. Having stored heat during the day, these building elements will release the heat content later in the evening, partly to indoor space, which with presence of sufficient time-lag can be dissipated by use of cooler outdoor air via natural ventilation, and partly to outdoors which can be accelerated by clear-sky radiation [14]. Additionally, the increased gradient between indoor warmer and the outside cooler environment will improve this purging process [17]. A thermal insulator decelerates the transfer of heat between different areas at different temperatures [14] and limits heat loss through the building fabric in winter and inward heat flow in summer.

Simple steady-state calculations ignore the (realistic) dynamic processes apparent in real buildings. Non-steady state, *i.e.*, dynamic, calculation methods permit evaluation of the thermal performance of buildings under real conditions. Such methods employ various parameters for including the mass effect in thermal performance analysis and methods vary in complexity. CIBSE presents the Admittance procedure which requires the calculation of three parameters: Admittance value (*Y*-value), decrement factor (*f*) and surface factor (*F*) in addition to thermal transmittance (*U*-value) [18]. Admittance relates to the storage of energy in the room surfaces following fluctuations in internal temperature. The Admittance value describes the ability of a material to exchange heat with a space, for each degree of deviation of the space temperature about its mean value [18]. The key variables involved in determining Admittance are heat capacity, density, thermal conductivity, surface resistance and the length of time available to get heat in and out of the material, which is typically assumed to be 24 h [19]. Accordingly, it is a function of the diffusivity and thickness of materials and can be considered as a cyclic *U*-value. The Admittance *Y*-value has the same units as the *U*-value (W/m^2 K). Greater Admittance confers lower amplitude indoor temperature fluctuations. Therefore, unlike *U*-values, high *Y*-values are desirable in a thermal mass perspective [18]. For a clearer differentiation between thermal admittance (*Y*-value) and thermal transmittance (*U*-value), it should be highlighted that it is possible to have different elements with the same insulation performance, indicated by the *U*-value, but different damping properties, indicated by the *Y*-value as presented in Table 1.

Table 1. Contrasting values of admittance and transmittance [14].

Element	***Y*-value (W/m^2 K)**	***U*-value (W/m^2 K)**
Typical heavyweight wall (brick/blockwork with cavity insulation)	4.0	0.6
Typical lightweight wall (cladding, insulation, lining)	1.0	0.6

The decrement factor (*f*) represents the relationship between the indoor and outdoor daily temperature swings [20]. A low value indicates that the building fabric is capable of dampening the indoor temperature range, relative to outdoors. For a thin structure with low thermal capacity the value will be unity and will decrease with increasing thickness and/or thermal capacity [18]. The surface factor is the ratio of radiant heat flow (from shortwave sources, e.g., the sun) readmitted to the space from the surface, to the heat flow incident upon the surface [18]. The benefit of applying a surface factor is in quantifying the absorption and subsequent release of transmitted solar radiation. Higher heat capacity results in lower surface factors and greater time lag [21].

2.2. Local Climatic Context

Tehran, located at 35N and 51E, features a semi-arid continental climate, according to the Koppen climatic classification, with hot dry summers and cold winters. Figure 1 presents a 5-year average (2005–2009) of mean monthly maximum and minimum temperatures from the Geophysics station of Tehran and Figure 2 presents the 5-year average relative humidity and rainfall for the same location.

Figure 1. Five year average of mean monthly maximum and minimum temperatures for Tehran (Geophysics station, 2005–2009).

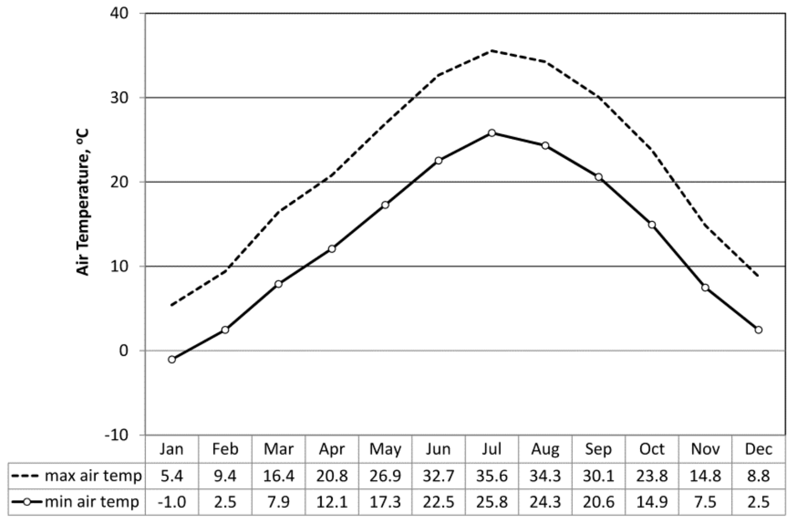
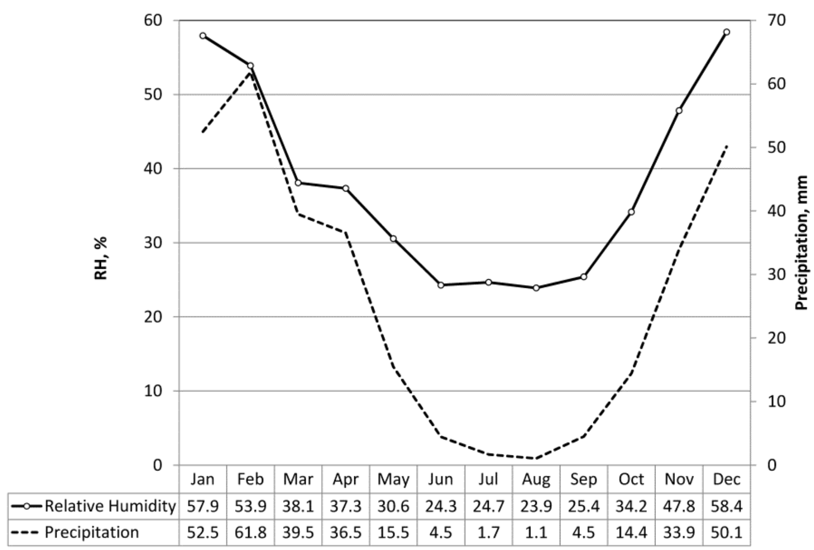
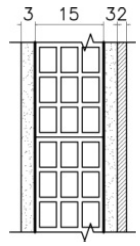
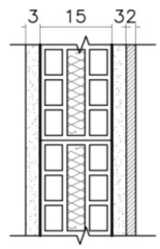
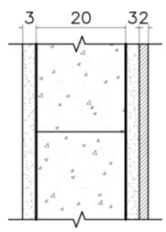
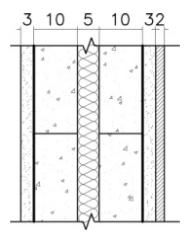
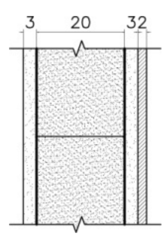
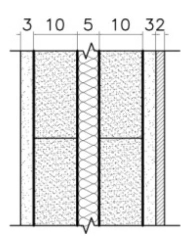


Figure 2. Five year average of mean monthly relative humidity and rainfall for Tehran (Geophysics station, 2005–2009).



Through interviews with people involved in the construction industry and field observations of the author, conventional wall constructions which are used in residential buildings of the city of Tehran have been categorized in Table 2.

Table 2. Categorization of conventional wall types.

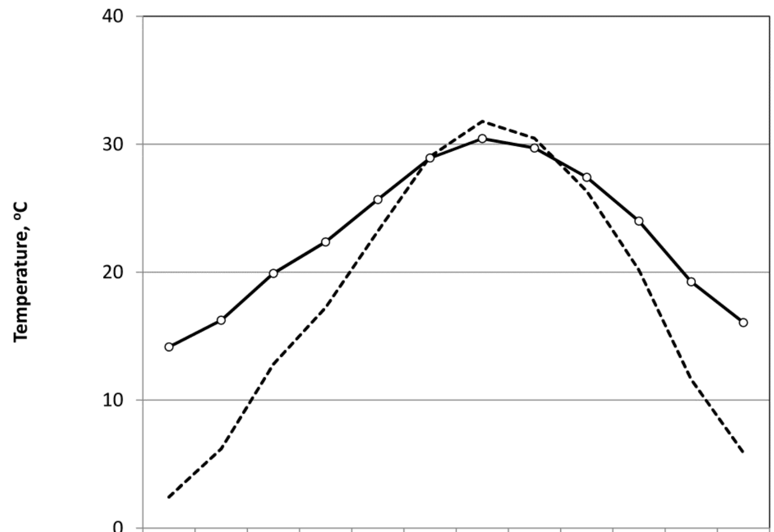
Wall reference and type	Construction materials	Detail	*U*-value ($W/m^2\ K$)	Thickness (cm)	Image of material
HCB1 Hollow clay block	Plaster lining (3 cm) Clay block (15 cm) Sand & cement mortar (3 cm) Exterior stone finishing (2 cm)		1.3	21	
HCB2 Hollow clay block	Plaster lining (3 cm) Clay block [15 cm with 2 cm expanded polystyrene (EPS)] Sand & cement mortar (3 cm) Exterior stone finishing (2 cm)		1.08	21	
L1 LECA block	Plaster lining (3 cm) LECA block (20 cm) Sand & cement mortar (3 cm) Exterior stone finishing (2 cm)		1.34	28	
L2 LECA block	Plaster lining (3 cm) LECA block (10 cm) Cavity filled with expanded polystyrene (EPS) (5 cm) LECA block (10 cm) Sand & cement mortar (3 cm) Exterior stone finishing (2 cm)		0.41	33	
A1 AAC block	Plaster lining (3 cm) AAC block (20 cm) Sand & cement mortar (3 cm) Exterior stone finishing (2 cm)		0.71	28	
A2 AAC block	Plaster lining (3 cm) AAC block (10 cm) Cavity filled with expanded polystyrene (EPS) (5 cm) AAC block (10 cm) Sand & cement mortar (3 cm) Exterior stone finishing (2 cm)		0.37	33	

Walls are most commonly made of hollow clay blocks, LECA (Lightweight Expanded Clay Aggregates) and AAC (Autoclaved Aerated Concrete) blocks, with clay blocks being the most popular choice. Some practitioners favor the use of LECA over clay blocks due to a perceived thermal damping performance advantage. However, the results of this investigation indicate that LECA by itself is not the better choice, although LECA when combined with insulation does have significant benefits with regards to the attenuation of outdoor temperature swings. The application of AAC is less common due to some construction difficulties pertaining to a lack of adhesion between interior plaster and the AAC block. Based on the adaptive comfort standard, originally proposed by Humphreys and Nicol [22], Heidari [13] introduced an equation for the calculation of the comfort temperature for the people of Tehran. Comfort, or "neutral", temperature is the temperature at which people feel neither warm nor cold and is calculated using the monthly mean outdoor temperature as presented in Equation (1):

$$T_{comf.} = 0.555\, T_{out} + 12.8 \quad (1)$$

A field-study methodology was employed by Heidari [13] and results showed good agreement between comfort temperature and mean outdoor temperature. The findings of Heidari's study [13] revealed that the people could achieve comfort at higher indoor air temperatures compared with the recommendations of international standard ISO 7730 [12]. According to adaptive comfort standards, the human body is capable of adapting to its environment. Therefore, as indicated by Equation (1), in different months of the year the human body feels comfortable at different temperatures. $T_{comf.}$ for each month is presented in Figure 3 which has been calculated based on mean monthly temperature (5-year average) for the Geophysics station of Tehran. Whilst Heidari's field-based study encompassed both hot and cold seasons and presents findings that suggest the building occupants are accepting of both higher indoor air temperatures and a higher overall range of temperatures, the data were gathered from occupants in offices that ranged in indoor temperatures from approximately 21.8 °C to 33.2 °C and, therefore, the prediction of comfort temperatures outside of this range must be treated with some skepticism. However, our analysis seeks to use this simple metric as a proxy for space conditioning energy use; accepting possible shortcomings as a precise indicator of thermal comfort in mid-Winter months. For example, it would seem reasonable to suggest that a "free-running" building exhibiting a large deviation from a given comfort temperature will require more energy input in terms of mechanical heating or cooling than a building that is already close to the comfort temperature by virtue of its improved thermal envelope performance. Accordingly, employing Equation (1) to determine a base temperature, in a similar way to the application of Heating or Cooling Degree Days, provides a useful simple indicator of building energy performance that can be used to compare different thermal envelope solutions.

Figure 3. Mean monthly outdoor and occupant comfort temperature for Tehran.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean monthly outdoor temp.	2.4	6.2	12.8	17.2	23.2	29.0	31.8	30.5	26.3	20.2	11.6	5.9
Tcomf.	14.2	16.2	19.9	22.4	25.7	28.9	30.4	29.7	27.4	24.0	19.2	16.1

3. Simulation

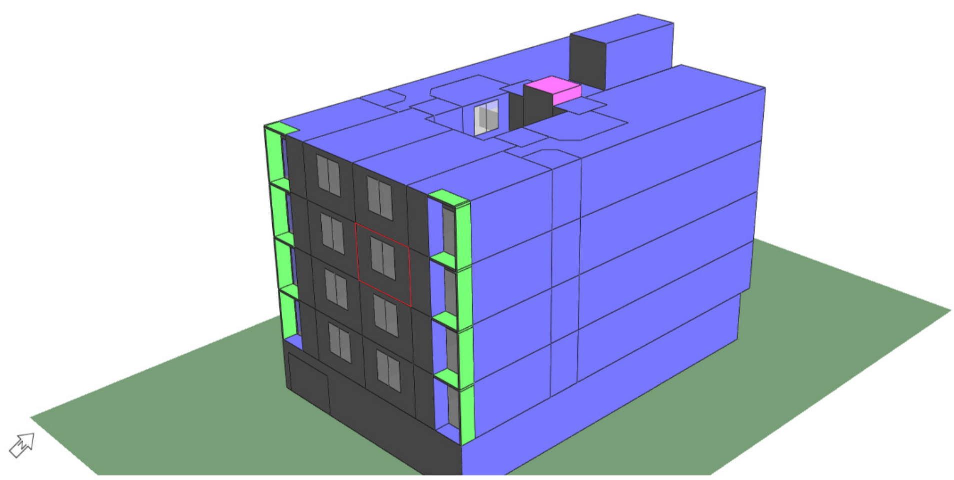
In order to study and analyze how different wall constructions perform under dynamic outdoor weather conditions, the thermal simulation package IES-ve was used. This tool is able to simulate the performance of a building under non-steady state conditions using real climate data, in this case for the city of Tehran. Some limitations exist in the representation of certain wall types in the simulation model, namely the effect of heat flow in parallel through the hollow core blocks. The input of the thickness of each layer of material in to the model does not permit the inclusion of different materials in the same plane, thus in walls that contain hollow core blocks with regular rectangular voids the material of the highest proportion in that plane was used, which is either air or expanded polystyrene insulation. This ignores the effect of the thermal bridge across the air or insulation layers, however, the dynamic performance is controlled mainly by the properties of the materials immediately adjacent to the interior, e.g., plaster, *etc*., thus the presence of the bridge has little effect. In the wall types simulated in this study the inner layers comprise 30 mm of plaster followed by the first solid plane layer of the hollow block, providing at least 45 mm of material before any bridge is reached.

3.1. Simulation Scenario

In this study, all sources of internal casual gains were omitted for running the IES simulation; ventilation, in the form of infiltration was included at a continuous background rate of 0.5 Air Changes per Hour (ACH) to represent expected typical air leakage through the fabric of the building. Accordingly, no heating/cooling system, occupant, lighting or appliance profiles (for internal heat gains) were defined or considered in the model. This approach was to make a clear evaluation of the performance of the building's fabric energy system when exposed to dynamic weather conditions. The geometric representation of the building in IES is presented in Figure 4.

The building is intended to represent a typical Tehran apartment block with a ground floor parking area plus four levels of accommodation above. This study is interested in the evaluation of different external wall constructions and, therefore, an intermediate (3rd Floor) level room was selected for detailed analysis. The room selected for analysis is outlined in Figure 4 and is south-facing and measures 3.45 m wide × 5.40 m deep and 2.80 m high. An argon-filled double-glazed window unit is located centrally in the external wall and measures 1.6 m × 1.7 m. Intermediate floors/ceiling are constructed from lightweight concrete beam and block units with ceiling level gypsum plaster finish and floor level ceramic tiles (U = 1.4 W/m^2 K). Internal walls are lightweight concrete block with a plaster finish. In all simulations only the external wall is modified and all other elements remain fixed. Materials and construction systems were analyzed and compared in terms of their basic thermal properties such as density (ρ), specific heat capacity (C), thermal conductivity (λ), diffusivity (α) and their derived thermal properties including thermal admittance (Y), effective thermal mass (C_m), and decrement factor (f). Finally, indoor temperature was compared to the region-specific comfort temperature to demonstrate the ability of each fabric system to provide thermal comfort for occupants.

Figure 4. Integrated Environmental Solutions Virtual Environment (IES-ve) Pro 3-D model of a typical Tehran apartment building.



4. Results and Discussion

Dynamic simulation results provide valuable additional information in relation to wall type performance and result in a different appraisal of the optimum solution than would be found from U-value-based performance alone. The dynamic thermal performance of the building envelope is dependent upon three basic properties, namely, heat capacity, density, and thermal conductivity. Higher heat capacity and density maximize the amount of heat absorbed in every m^3 of the material and a moderate thermal conductivity is needed for a material to make its heat capacity advantageous. A moderate thermal conductivity enables the material to exchange heat with ambient air at an appropriate rate; some materials such as wood have high heat capacity but due to their relatively low thermal conductivity the heat exchange rate is so slow that their heat capacity would become ineffective [19]. The combination of these parameters is often expressed as thermal diffusivity (α), as presented in Table 3.

The thermal diffusivity of a material is a measure of how fast the material temperature adapts to the surrounding temperature. The lower the diffusivity, the greater the time-lag of a material [23]. Therefore, for the same geometry and configuration, of the materials presented in Table 3, AAC and LECA would have less rapid response to temperature changes than clay or brick. It should be stated that the shape and configuration of the final construction product, e.g., hollow or solid blocks will clearly affect thermal performance of the whole construction. The thermal properties including derived parameters for each wall type are presented in Table 4.

Table 3. Material thermo-physical properties.

Material	ρ (kg/m^3)	λ (W/m K)	*C* (J/kg K)	Diffusivity α, (m^2/s)
Brick	1700	1	840	7.00×10^{-7}
Clay	1300	0.5	837	4.60×10^{-7}
LECA	900	0.23	1000	2.56×10^{-7}
AAC	700	0.17	1000	2.43×10^{-7}
EPS	15	0.04	1340	1.99×10^{-6}

Table 4. Thermal properties including derived parameters for each wall type.

Wall ref.	*U*-value (W/m^2 K)	C_m (kJ/m^2 K)	Admittance (W/m^2 K)	*f*	*F*	Thickness (m)
HCB1	1.30	71.5	3.52	0.81	0.72	0.21
HCB2	1.09	71.7	3.64	0.80	0.73	0.21
L1	1.34	72.5	3.57	0.81	0.71	0.26
L2	0.41	72.5	4.01	0.44	0.70	0.31
A1	0.71	94.5	3.77	0.39	0.69	0.26
A2	0.38	94.5	3.86	0.29	0.68	0.31

f: Decrement factor
F: Surface factor
C_m: Effective thermal mass [a]

[a] Effective thermal mass is the product of density, thickness and heat capacity for each layer until one of the following three criteria is met: Working from inside to outside (i) 100 mm point is reached; (ii) Mid-point of the element is reached; (iii) Insulation layer is reached.

Based on a steady-state appraisal wall type A2, with the lowest *U*-value, has the best thermal performance and due to its lowest decrement factor the greatest capability with regards to attenuation of external temperature swings. However, wall type L2 has the highest thermal admittance (*Y*-value) and, as this value is calculated by considering many different thermal and physical properties, e.g., heat capacity, thermal conductivity, density, *etc*., it can be concluded that this value can help to realize how effective a material will be in practice. Therefore, it is expected that L2 with *Y*-value of 4 is most capable of dampening weather conditions. In winter months the different wall types perform more according to their respective *U*-values than in summer months. This is because, as discussed by a number of authors, for example Givoni [24] and also De Saulles [19], the use of thermal mass is more advantageous when thermal conditions are fluctuating and the outdoor temperature is cycling below and above the indoor temperature. In other words, in cold weather conditions T_{in} is always higher than

T_{out}; therefore, heat flow occurs in one direction, from inside to outside. While in summer months building fabric is subject to both outward and inward heat flow and this is the phenomenon which challenges the primary assumptions inferred from steady-state calculations. Accordingly, in the summer months, instead of having distinct records of indoor temperature for each of the different wall types corresponding to their differing *U*-values, as is the case in the winter condition (Figure 5), internal temperatures begin to overlap one another during each 24-h period (Figure 6). This effect can be highlighted through comparison of A1, A2 and L2 performances in winter and in summer. A2 and L2 (with very similar *U*-values) have similar performances in winter (Figure 5); while in summer A1 and A2 (with very different *U*-values) perform similarly to one another, whilst L2 now exhibits very different response to A2 (Figure 6). This is due to thermal mass of these materials being effective in fabric interaction with its environment.

Figure 5. Outdoor temperature and indoor room temperatures for different wall constructions, for a seven day winter period.

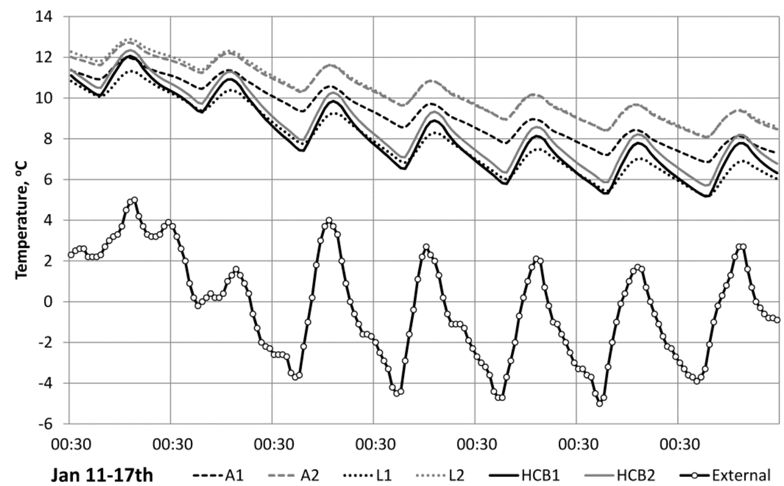
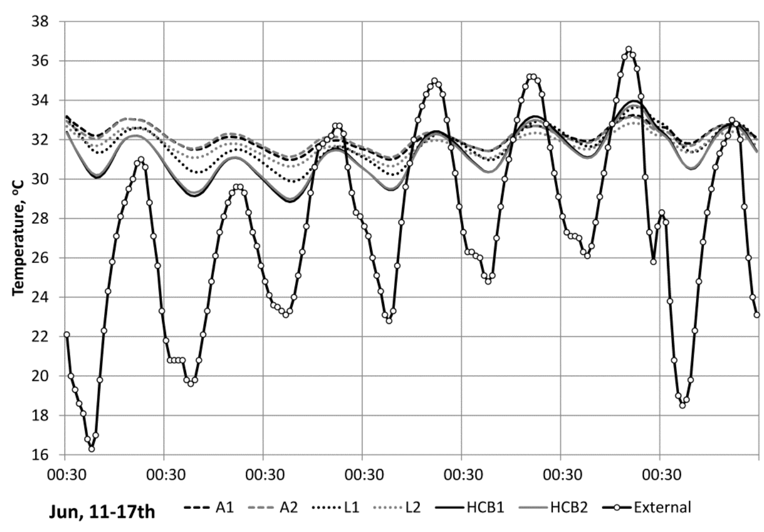
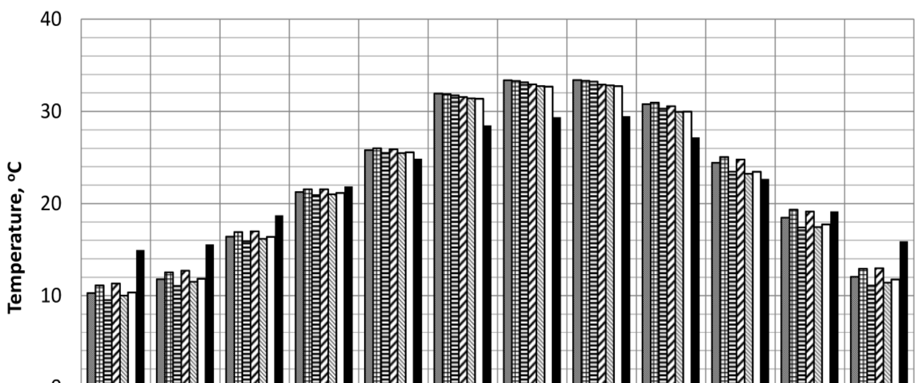


Figure 6. Outdoor temperature and indoor room temperatures for different wall constructions, for a seven day summer period.



Plotting the indoor temperature against the region-specific comfort temperature for each wall type (Figure 7) enables comparison of the degree of deviation from the comfort temperature. As indicated in Figure 7, in the colder months of January, February, March, April, November, and December, wall types L2 and A2, as was expected from their lower *U*-values, provide a higher degree of comfort for the building occupants whereas in the warmer months of the year, *i.e.*, May, June, July, August, September, October these wall types plus wall type A1 show a slightly greater deviation from the comfort temperature than the other wall types. For wall types L2 and A2 this is because, on summer nights when the outside temperature (T_{out}) falls below the indoor temperature (T_{in}), the insulation layer inside these wall types resists the outward heat flow and causes delay in discharge of the thermal mass of the building and consequently higher indoor temperatures. In wall type A1, however, this inability to maintain comfortable room temperatures is mostly due to the heat which is absorbed and stored in the depth of the available mass (solid block) which makes the transient performance worse than wall type L2 despite having a lower *U*-value and a layer of insulation. Furthermore, as the simulated building does not benefit from ventilation and convective cooling effects, beyond the moderate 0.5 ACH background rate, this trapped heat results in higher temperatures for the subsequent day.

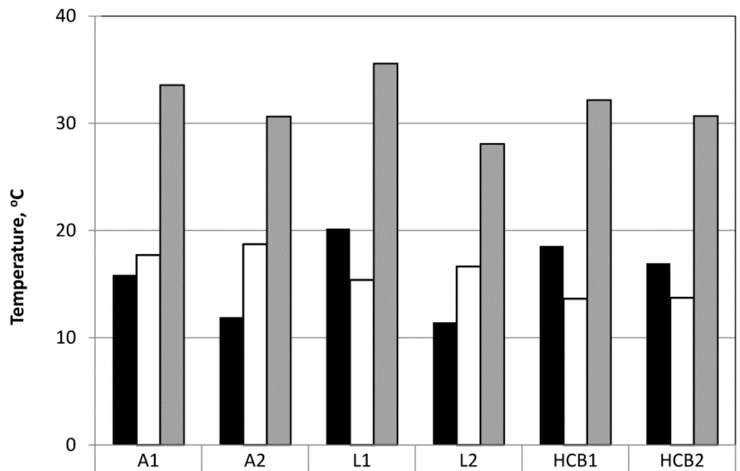
Figure 7. Monthly average indoor temperature for six different wall constructions compared with the comfort temperature.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A1	10.3	11.8	16.4	21.3	25.8	31.9	33.4	33.4	30.8	24.4	18.5	12.1
A2	11.1	12.5	16.9	21.6	26.0	31.9	33.3	33.3	31.0	25.1	19.3	12.9
L1	9.5	11.1	15.9	20.9	25.5	31.7	33.2	33.2	30.3	23.5	17.4	11.1
L2	11.3	12.7	17.0	21.6	25.9	31.6	32.9	32.9	30.6	24.8	19.1	13.0
HCB1	10.0	11.5	16.2	21.0	25.5	31.4	32.8	32.8	30.0	23.2	17.4	11.4
HCB2	10.4	11.8	16.4	21.2	25.6	31.4	32.7	32.7	30.0	23.5	17.7	11.8
Tcomf.	15.0	15.6	18.7	21.8	24.9	28.5	29.4	29.5	27.2	22.7	19.1	15.9

Annual performance of wall types is presented in Figure 8, which indicates the deviation of T_{in} from $T_{comf.}$ in summer (positive) and winter (negative) for an entire year. The summary of dynamic thermal properties for the six wall types (Table 4) shows that walls HCB1, HCB2 and L1 have higher decrement factors resulting in greater indoor temperature swings with relatively short time lags and lower effective thermal mass.

Figure 8. Annual average deviation of indoor temperature from comfort temperature for six different wall constructions.



	A1	A2	L1	L2	HCB1	HCB2
■ Negative deviation	15.8	11.9	20.2	11.4	18.5	16.9
□ Positive deviation	17.7	18.7	15.4	16.6	13.6	13.7
▩ Total	33.5	30.6	35.6	28.1	32.2	30.7

The summer-time performance, as indicated by the positive deviation in Figure 8, indicates that HCB1, HCB2, and L1 perform better than the other three wall types but that A1, A2 and L2 have better performance in winter. However, the sum for wall types L2, A2 and HCB2 reveals the lowest total deviation of T_{in} from $T_{comf.}$, which supports the application of insulation in such walls. The application of wall type L2 in place of L1, results in 7.5 °C decrease in deviation of T_{in} from $T_{comf.}$, leading to reduced energy demand for conditioning of the space. Heidari [13] estimates that each degree reduction in heating/cooling loads results in 7% energy saving.

5. Conclusions

The aim of this research was to evaluate the thermal performance of modern wall constructions which are commonly used in place of their traditional counterparts in the new residential buildings of Tehran. The findings of this investigation can be summarized as follows: the steady-state calculation alone is not a true indication of thermal performance of building fabric under real climatic conditions. Additionally, the thermal insulation materials and thermal mass have different roles in the thermal performance of the building fabric energy system. Dynamic simulation using local weather data provides useful, cost-effective, insight in to these relative merits and the behavior of zones comprising different building envelope materials. In the absence of dynamic simulation, the appraisal of other performance indicators, such as the *Y*-value (Admittance), could provide useful guidance as part of simple standardized dwelling designs for use in building compliance codes such as Code No. 19. Whilst time-averaging such data removes some of the detail it does permit comparison with simpler methods including monthly average thermal comfort temperatures, which provides a useful parameter for appraisal of building performance when comparing the merits of many different wall types. This analysis shows that whilst wall type A2 has the lowest *U*-value amongst the introduced wall types, wall type L2 has the best overall performance in terms of moderating weather conditions and providing thermal comfort for occupants over a complete year. The intelligent use of natural ventilation, most likely employing night-time ventilation, could improve further thermal comfort and future work evaluating the optimization of such strategies is recommended.

Conflicts of Interest

The authors declare no conflict of interest.

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