Scientific Paper / Artículo Científico

UNIVERSIDAD POLITÉCNICA SALESIANA ECUADOR
INGENIUS
Revista de Ciencia y Tecnología
https://doi.org/10.17163/ings.n28.2022.10
pISSN: 1390-650X / eISSN: 1390-860X

Comparative analysis of thermal comfort of a single-family house in LSF and brick masonry

Análisis comparativo de confort térmico de vivienda unifamiliar en LSF frente a mampostería

Rodrigo Brito-Peña[1,*], Daniel Villa-Enderica[1], Esteban Zalamea-León[1]

Received: 16-05-2022, Received after review: 17-06-2022, Accepted: 20-06-2022, Published: 01-07-2022

Abstract

Residential construction in Ecuador has recently grown a 35.6%. The typical construction system for housing envelopes is concrete block or brick; construction in Light Steel Framing (LSF) or galvanized steel frames is emerging. To solve the housing demand, the thermal comfort inside a two-story one-family home in the city of Cuenca is evaluated considering both construction systems, to know the comfort standards offered by homes in accordance with the Ecuadorian Construction Standard (NEC, Norma Ecuatoriana de la Construcción). The research was carried out with Design Builder and Therm, where the parameters that influence the energy performance of homes are analyzed. Under local conditions, the predominant system reaches annual hourly thermal comfort values of 51%, but the LSF system reaches 62%. However, with improvement strategies in the overall envelope, the LSF reaches 86%. The variables in decreasing order of thermal influence were: air infiltrations, envelope construction system and housing deployment. In Cuenca it is feasible to use the LSF with minimum insulation to reach acceptable levels of comfort, being an adequate alternative to be promoted for building one-family housings.

Keywords: Housing, Light Steel Framing, Thermal comfort, Simulation

Resumen

La construcción residencial en Ecuador ha crecido un 35,6 %. El sistema constructivo típico para envolvente de viviendas es de bloque de concreto o de ladrillo, la construcción en LSF (Light Steel Framing) o marcos de acero galvanizado (LSF) está en surgimiento. Para solucionar la demanda habitacional se evalúa el confort interior térmico de una de vivienda unifamiliar de dos plantas en la ciudad de Cuenca con ambos sistemas constructivos para conocer los estándares de confort que ofrecen las viviendas en concordancia con la Norma Ecuatoriana de la Construcción (NEC). La investigación se realizó con Design Builder y Therm donde se analizan los parámetros que influyen en el desempeño energético de las viviendas. Con las condiciones locales, el sistema predominante alcanza valores de confort térmico horario anual del 51 %, pero el sistema LSF alcanza un 62 %. Sin embargo, con estrategias de mejoramiento en la globalidad de la envolvente, el LSF alcanza el 86 %. Las variables en orden de mayor a menor influencia térmica resultaron: infiltraciones de aire, sistema constructivo de la envolvente e implantación de la vivienda. En Cuenca es posible el uso del LSF con aislamiento mínimo para alcanzar niveles aceptables de confort, siendo una alternativa adecuada a promover para edificar viviendas unifamiliares.

Palabras clave: vivienda, *steel frame*, confort térmico, simulación

[1,*]Dirección de Investigación de la Universidad de Cuenca, Universidad de Cuenca, Ecuador.
Corresponding author ✉: jrodrigo.britop@ucuenca.edu.ec.

Suggested citation: Brito-Peña, R.; Villa-Enderica, D. and Zalamea-León, E. "Comparative analysis of thermal comfort of a single-family house in LSF and brick masonry," *Ingenius, Revista de Ciencia y Tecnología*, N.° 28, pp. 100-124, 2022, DOI: https://doi.org/10.17163/ings.n28.2022.10.

1. Introduction

For each particular context it is important to establish comparative analyses of different construction technologies, to set capabilities in terms of security, durability, quality, thermal comfort, among other aspects. It has been evidenced that the thermal performance of dry construction systems such as Lightweight Steel Framing (LSF) may reach conditions similar to those of masonry [1], and it is possible to define insulation levels appropriate for the context.

According to the American Institute of Architects (AIA, 2007), 50% of the worldwide emissions of greenhouse gases were produced by the construction industry. To a large extent, this is a consequence of the high consumption of buildings and the lack of comfort in them. An impact is generated from the manufacturing, transportation execution, use and maintenance of the building up to the end of its life cycle [2]. Likewise, construction is placed as the second industry with the highest energy demand worldwide, and most of such consumption is used for achieving indoor environmental quality [3,4]. Therefore, it is important to determine the capability of the construction materials to achieve quality in thermal comfort with high degree of construction efficiency [5,6]. In the last fifteen years, the construction sector in Ecuador has grown 35.6% due to the economic and population development. Among the total number of construction permissions granted in 2018, 84.1% correspond to residences, 56.9% correspond to one-family housings and 88.1% are new housings.

The predominant materials for housings in Ecuador are reinforced concrete for foundations, structure and roof, concrete block or brick masonry for walls and envelopes, structured in steel for constructive speed. The introduction of alternative construction systems is minimum, and very little consideration is given to the affectations due to the materials selected. The housing in LSF dry construction has a share of only 2.9 % in Ecuador [7], as seen in Figure 1 [7]. The systems that enable prefabrication are an opportunity to reduce the construction cost, but the comfort levels should be also considered [8].

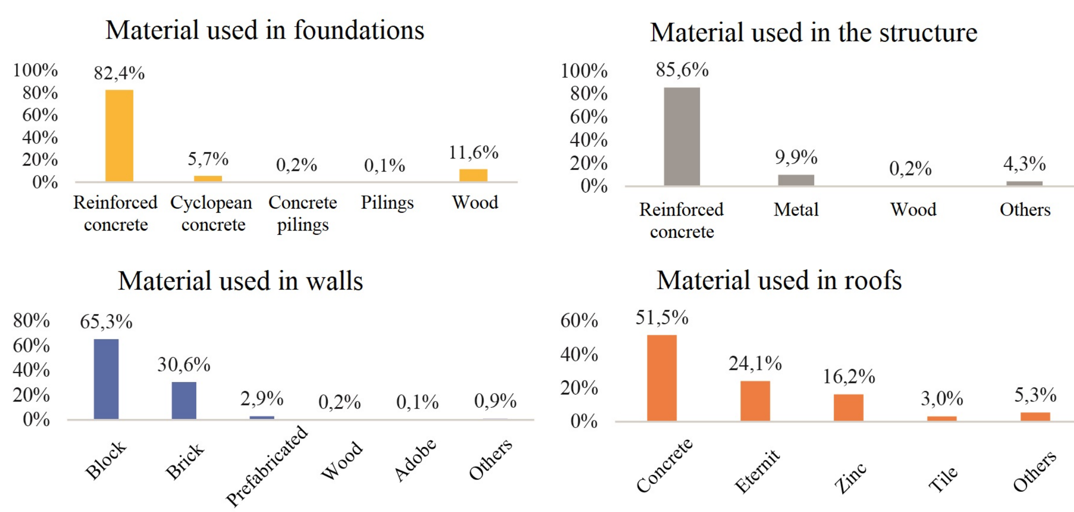


Figure 1. Main materials that predominate in the construction in Ecuador

The implementation of the LSF dry system may result less offensive with the environment, and offers great advantages compared to traditional wet systems regarding its *in situ* impact [9]. Various constructive advantages are typical of this system, such as the potential prefabrication and speed, durability, seismic-resistant capability, convenient prices, among others [10]. The LSF has a good thermal performance since it enables including the insulation required and calibrated according to the local conditions; it has the capability of reaching high levels of thermal insulation, even in extreme weather [11, 12].

In addition, according to [9, 13], the main deficit regarding the thermal capacity in the LSF is in the thermal bridges as a consequence of the light steel structural frames which should not be more than 0.60 m apart. With respect to structural capacity, the LSF has appropriate conditions due to the lower rigidity and weight, which implies that the seismic response is adequate in regions of high seismicity, such as the Andean zone [14, 15]. Likewise, it responds favorably to accidental loads [16].

In terms of safety in the event of fire, the LSF is recommended over other flame-retardant technologies [17]. At the same time, it is capable of integrating all components necessary to construct a building. The construction methods are manufacturing on-site, by prefabricated panels and, finally, the modular construction [18]. The LSF tends to be more expensive compared to masonry housings typical in Ecuador, due to the reduced penetration of the material. However, it may result a convenient system due to the advantages of industrialization and market economy [19]. It reduces the labor costs between 62.5% and 73%, and improves management of consumables, operations and logistics at the construction sites [20]. In Ecuador, the deficit in housings together with the difficult economic situation causes the construction of low-budget buildings using handcrafted materials, and those housings do not fulfill the appropriate levels of thermal comfort, and thus, new buildings should meet NEC standards [21].

1.1. Climatic conditions of the surroundings of the housing under study

Ecuador is divided in six climatic zones, according to what is established by the ASHRAE 90.1 and Miduvi [22]. The reference housing is located in climatic zone 3 of Ecuador, determined as a region of rainy continental mountains. Figure 2 shows a diagram of the climatic conditions 3). The zone is very close to the Equator, at an altitude of 2550 m above sea level; due to these conditions, it is a temperate and stable climate all year round. The temperature varies between maximum and minimum averages of 7 and 25 °C; however, extremes of −1.7 °C and 28.9 °C are recorded, with an average of 15.6 °C. March is the hottest month and August the coldest one, but the extreme conditions of cold or hot normally do not last more than a few hours. Due to the Equatorian conditions, seasonal climatic variations are minimal. The duration of the day is also stable all year round, with the dawn occurring between 05:50 and 6:30 and the dusk between 18:05 and 18:35, depending on the season. The wind is low, with preponderance from the Northeast. Consequently, it is about a temperate weather with greater incidence of excessive cooling, but with a weather benign for habitability; most buildings lack active conditioning systems. However, this aspect implies that out of comfort moments are usual.

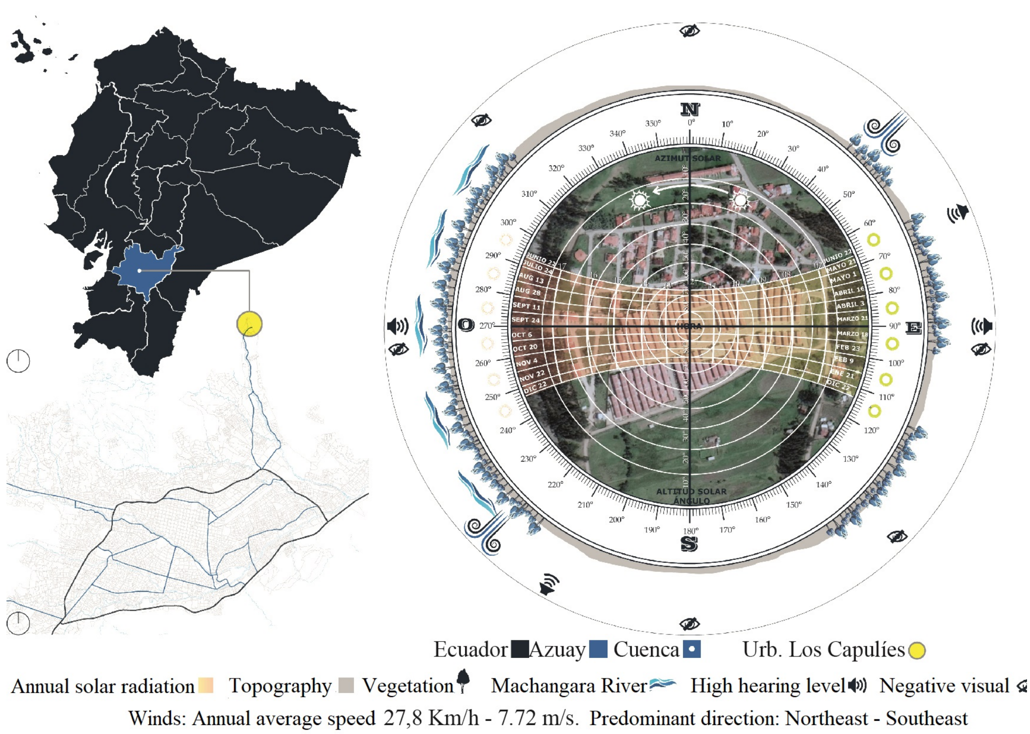


Figure 2. Location and scheme of the climatic conditions of the surroundings

It will be analyzed a housing with spatial and morphological features that are recurrent in the country, with the most frequently used construction system consisting of masonry and concrete, with the objective of determining the base environmental conditions. On that basis, variations are compared according to the change of envelope in the LSF construction system. For this purpose, simulations are programmed to contrast the thermal behavior of the same housing materialized in two different construction systems and envelopes, LSF system vs. traditional system, assuming the same functional and spatial conditions. It is analyzed the type II model of one-family housing found at the residential area Los Capulíes, located at Cuenca, which was developed by the Housing Ministry (Miduvi, Ministerio de la Vivienda) of Ecuador. These housings are arranged in high-density settings, paired on both sides to achieve a maximum leverage of the piece of land. The distance between the fronts is only five meters, whereas the backs are three meters apart. This arrangement reduces solar incidence, and also causes visualization and privacy problems. Figure 3 shows the configuration of the housings (based on documents of the Emuvi EP). Even though it has aspects regarding design conditions, this work analyzes the influence of envelope materials.

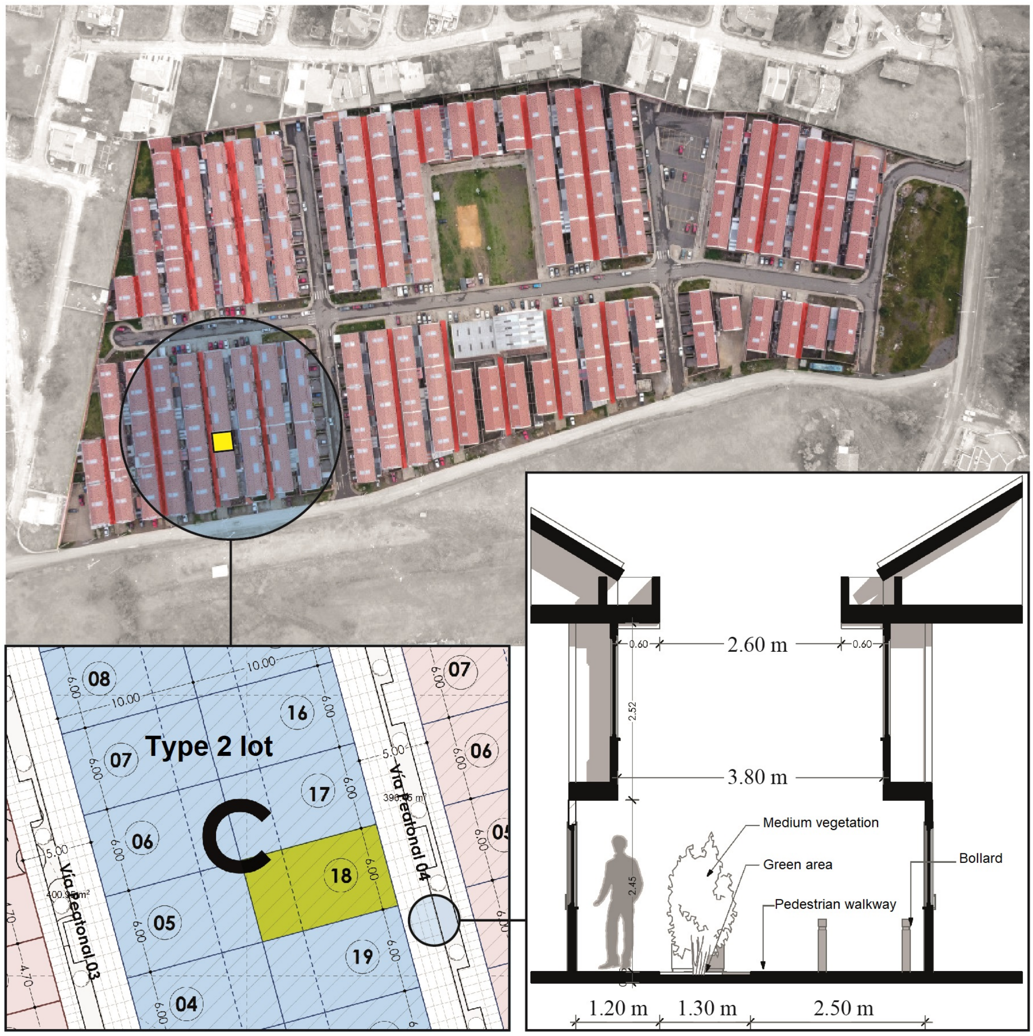


Figure 3. Housing under study together with the remaining housings in the residential area Los Capulíes

2. Materials and methods

At first instance, the parameters and features that have influence on energy performance were established, and analyzed with respect to the levels of thermal comfort of the regulation that dictates that the indoor temperature should be maintained between 18 and 26 ºC [23]; it is considered that excesses or deficits imply being out of the range of thermal comfort. With this precedent, the following parameters were determined for studying energy performance:

Deployment: It is determined by the position of the housing within the block, corresponding to a corner, middle or isolated housing. Weather: It is determined by means of the climatological archive of the Cuenca region. Internal thermal gains: It is referred to the amount of energy as heat within the housing, contributed by electric appliances and users. Air infiltrations: Make reference to the air exchanges per hour at a pressure of 50 Pa, i.e., to the levels of air renewal inside a housing.

These parameters will be studied in three variations of the same housing, according to its location within a block: isolated, middle and corner.

Eighty-five models were constructed for the analysis, from virtual variations of the materials. The indoor operating temperature (OT) is considered the variable for the analysis of results; the dry bulb external temperature (ET) only represents the temperature that affects the housing envelope and enables reflecting the level of conditioning reached by the housing. Regarding the levels of infiltration of this type of structures, indicators found in Chile [24] are considered since there are no local studies. Lower levels of air infiltration (10 ACH50) are expected in the masonry envelope, compared to the 25 ACH50 expected in the LSF. However, when the LSF is constructed with greater insulation, materials of better thermal performance and high construction quality, with emphasis on the constructive joints, the air exchanges decrease [25].

At a second instance, digital models of the one-family housing to be studied were made in two groups. The recurrent configurations and materials for the region, i.e., the traditional wet system, were modeled in the first group. The models with the LSF system were made in the second group. Finally, the indoor thermal comfort of the two construction systems was analyzed at a third instance. Virtual models were studied with the Design Builder [26] and Therm [27] energy simulators, fed by 2016 climatic information of the region under study. The climatic file (.tmy) (typical average climate) was not used, because it implies to lose days and hours with extreme temperatures; hence, it was used climatic data corresponding to one year (2016) in the epw file.

The evaluation was performed in sequential stages, due to the interaction of different factors that have influence on the indoor thermal comfort. The first stage seeks to determine the incidence of orientation, a diffuse aspect in the equatorial weather. Prior to analyzing the thermal comfort of the housing, in the second stage it is intended to determine with Design Builder the energy performance of the housing with LSF, without including thermal insulation. The model is fed by envelope coefficients from the thermal analysis of the materials carried out in Therm, tool that enables to determine in detail the insulation capacity considering affectations implied by thermal bridges. In the third stage it is sought to know if there are improvements in the thermal levels with minimal insulations in the LSF system. Finally, in the fourth stage it is sought to improve the materials used in the LSF system, with the purpose of knowing if the thermal increase is significant; thus, the Therm tool is used again to analyze the configurations of the different carpentries.

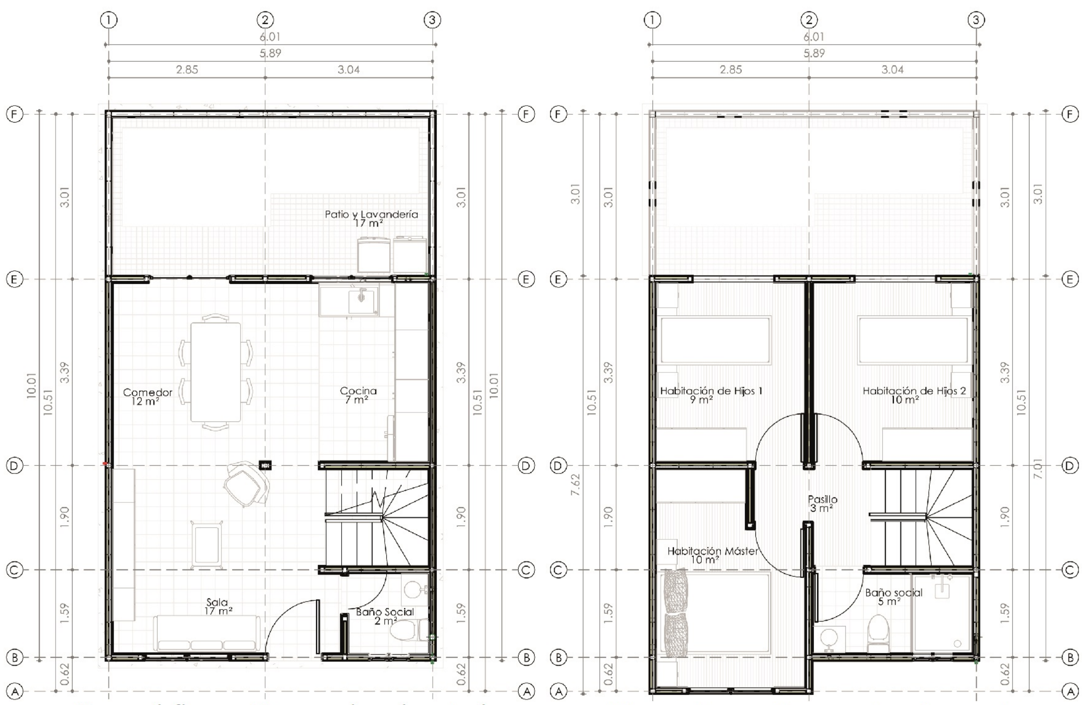
The requency Thermal Discomfort (FDT) is the percentage of time in which the operating temperature does not reach the required standards [28]. Therefore, in this research the results will be analyzed as percentages referred to a year in its 8760 associated hours. Likewise, the parameters or variables with higher or lower incidence on the thermal performance of the housing will be established in the final instance.

2.1. Original features and materials of the housings under study

The reference housing is a two-story one-family housing of 86.40 m^2 which, according to the INEC, is a recurrent typology in the country. It is a housing with average size and condition to accommodate four inhabitants. The housing is constructed with steel structure, masonry brick walls for the envelope, with plaster only in the interior and fiber cement roof with a false plaster ceiling parallel to the fiber cement. The bottom and mezzanine floors are made of concrete, with porcelain coating in wet areas and floating flooring in dry environments. Finally, the carpentries are made of steel with simple glass. As a basis for comparison, the indoor thermal quality is simulated with these conditions; Figure 4 shows the reference housing.

Figure 4. Status of the housing under study in 2020

The LSF proposal adopts the same conditions of the base model. The structural dimensions are provided by the engineering department of the local distribution company. The recommended components are the following: Stud profiles (columns) of 90 × 0.93 mm in walls and trusses, Track (beams) of 90 × 0.93 mm in walls and trusses, Stud of 200 × 1.8 mm in mezzanine floor and Track 200 × 1,8 mm in mezzanine floor. However, the use and configuration of the layers of insulation and coating materials are not determined according to the thermal performance, due to the minimum use of this technology nationwide. Both suppliers and consumers choose the components and materials based on various criteria to build the housing. Figure 5 shows the plans of the housing adapted to LSF.



Ground floor – Proposal under study
N= +0.00
Esc__1:100

Upper floor – Proposal under study
N= +2.64
Esc__1:100

Figure 5. Proposal materialized with LSF

2.2. General conditions for the indoor thermal comfort study

The aspects and features of the envelope are identified as input data for the indoor thermal comfort analysis, and the parameters for the digital evaluation are established categorized in six groups (Table 1).

Table 1. General conditions and parameters

N.°	**Parameter**	**Code**	**Variables**	**Variable description**	**Comments**
1	Housing typology	V01	V. brick middle	Current status	Middle
2		V02	V. brick corner	Current status	corner
3		V03	V. brick isolated	Current status	isolated
4		V04	V. LSF middle	Proposal	Middle
5		V05	V. LSF corner	Proposal	corner
6		V06	V. LSF isolated	Proposal	isolated
7	Deployment	I01	Current east facade	Orientation of main facade	Current status
8		I02	Current west facade	Orientation of main facade	Current status
9		I03	North facade	Orientation of main facade	North
10		I04	South facade	Orientation of main facade	South
11		I05	East facade	Orientation of main facade	East
12		I06	West facade	Orientation of main facade	West
13	Weather	C01	Annual	Annual average	Average
14		C02	Coldest month	Monthly average	Average
15		C03	Warmest month	Monthly average	Average
16		C04	Coldest day	Coldest day in the year	All day long
17		C05	Warmest day	Warmest day in the year	All day long
18	Internal gains	GI1	Users	3.7	average [29]
19		GI2	Appliances and equipments	13.31 W/m^2	W/m^2
20	Air infiltrations of the construction system	SC1	10 in all stages	Brick and steel mixed system	Source: [30]
21	(Levels ACH at 50 Pa)	SC2	25 in stages 1 and 2, 10 in stages 3 and 7 in stage 4.	LSF System	Source: [30]

3. Results and discussion

3.1. First stage: Base thermal performance of the reference housing, current status

Twenty digital models were made in the first stage, divided in two groups according to the construction system. The first group analyzes the mixed system constituted by brick in a steel structure of the housings in their current deployment; this is the base situation. The second group is focused on LSF. Table 2 describes in detail the evaluation parameters for all simulations, considering infiltration levels in air replacements per hour (ACH) at a pressure of 50 Pa, under different orientations of the front facade through which the housing is accessed.

Table 2. Variation parameter in the First stage

N.°	Construction system		Housing typology	Deployment
	Tipe	Features		
E1_01	Brick and steel mixed system		Middle	East
E1_02				West
E1_03	10 ACH50	Traditional masonry housing	Corner	Este
E1_04				West
E1_05			Isolated	North
E1_06				South
E1_07				Este
E1_08				West
E1_09	LSF System		Middle	North
E1_10				South
E1_11	25 ACH50			Este
E1_12				West
E1_13		LSF housing without insulation	Esquinera	North
E1_14				South
E1_15				Este
E1_16				West
E1_17			Isolated	North
E1_18				South
E1_19				Este
E1_20				West

The models with the orientations of the front and back facades with the main openings, doors and windows, are considered favorable when they face east and west (higher solar incidence) and unfavorable when facing north and south (minimum incidence of irradiation as a consequence of the equatorial latitude). The predominant orientation of the winds is demonstrated in Figure 2. It is found that the average thermal variation is minimal due to the orientation, as shown in Figure 6. For the subsequent stage, only scenarios with unfavorable orientations will be studied, to visualize the results in the most extreme temperatures.

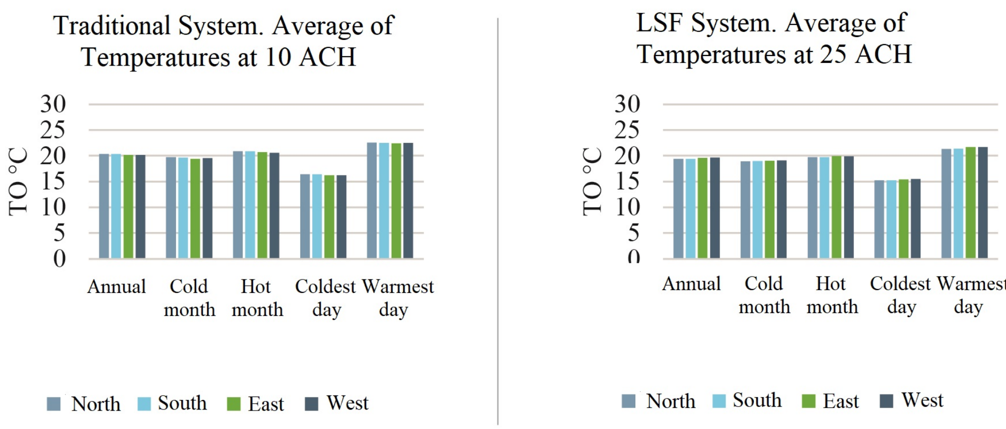


Figure 6. Average OT as a function of the Deployment parameter

3.1.1. Analysis of the thermal performance of the construction systems through the envelope section by means of THERM

The thermal transmittance of each envelope material of the construction systems under study, is analyzed in this section. The steel profiles that constitute the structure of the entire housing are added to the traditional system; such profiles are exposed in the original model. Likewise, the LSF is considered with a simple insulation through a 50 mm thick single layer of stone wool, with which there is a 40 mm remnant air layer in the envelope section. The variable of study is the influence of the metallic structure in each construction system. It is found the influence of the thermal bridges on the housings. The most unfavorable cases of each orientation are analyzed, as shown in Figure 7.

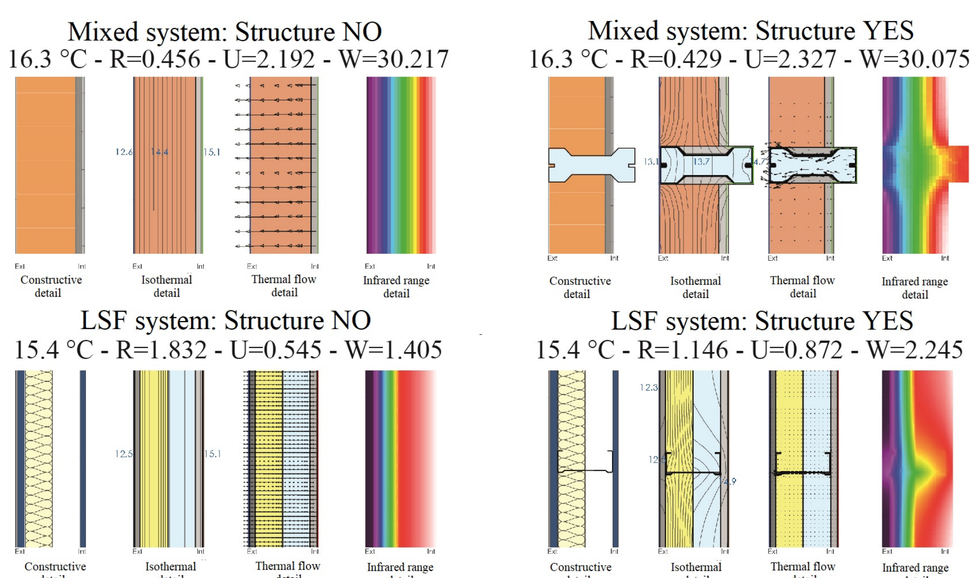


Figure 7. Thermal analysis of the section of both construction systems in THERM and conductivity determined

High values of thermal transmittance are evidenced in all the walls of the envelope, the thermal bridges are important in both construction systems, which significantly influences the insulation capacity. In the mixed construction system constituted by bricks in steel porticoes, higher values of thermal transmittance are observed in the zones in which structural elements meet. However, in the LSF, the thermal transmittance is spread and mitigated by the fiber cement and plaster cardboard coating.

3.2. Second stage: Thermal analysis with incidence of the thermal bridges in unfavorable orientations

At this stage (Table 3), the digital models are configured again in Design Builder, entering in the simulator the new values of the Thermal resistance parameter or R Factor of each material, values that are reduced to 67.78% of the original value according to the study by means of THERM. In this section, the housings are analyzed again with the condition of the Deployment parameter, referred in this case to the most unfavorable orientations, i.e., without direct solar incidence on facades.

Table 3. Second stage

N.°	Construction system		Housing	Facade
	Type	Features	typology	orientation
E2_01	Brick and steel mixed system		Middle	North
E2_02		Traditional masonry		South
E2_03	10 ACH50	housing	Corner	North
E2_04				South
E2_05			Isolated	North
E2_06				South
E2_07	LSF System		Middle	North
E2_08				South
E2_09	25 ACH50	LSF housing	Corner	North
E2_10		without insulation		South
E2_11			Isolated	North
E2_12				South

With the brick and steel envelope, in the case of the coldest day the housing is in comfort only at noon, whereas in the case of the warmest day, the comfort occurs in the morning and in the afternoon. An important peak in high temperatures is observed at noon. Consequently, the housing experiences overheating, since there is no insulation in the roof; specifically, overheating in the upper floor, as observed in Figure 8.

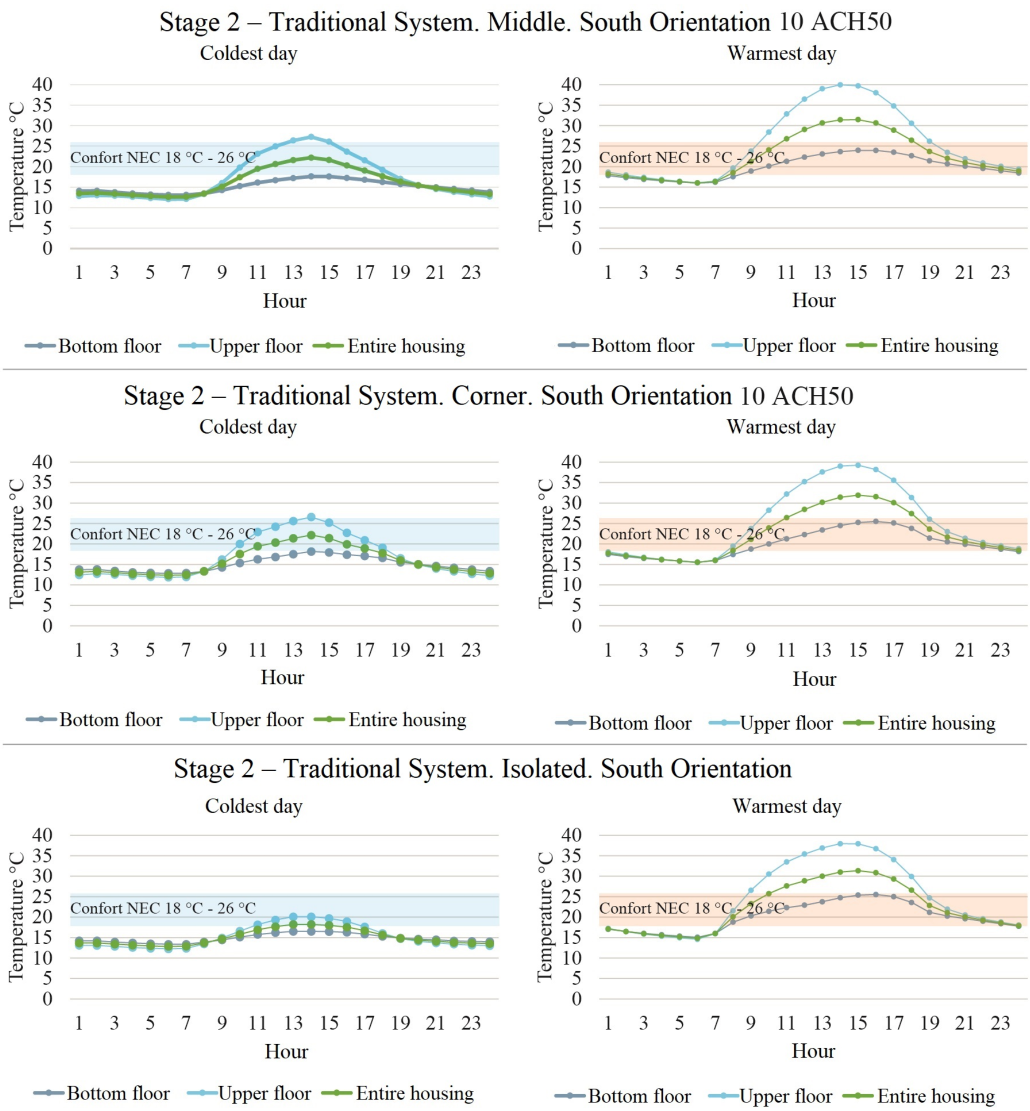


Figure 8. Thermal comparison, traditional system, second stage

For the coldest day in the LSF system, there is comfort after noon. However, in the warmest day the comfort extends for almost all day long. It is observed that the thermal curve tends to reduce the oscillation during the 24 hours of the day. The maximum and minimum peaks are less pronounced than in the reference system, as it is seen in Figure 9. Figure 10 shows the general thermal comparison of the second stage.

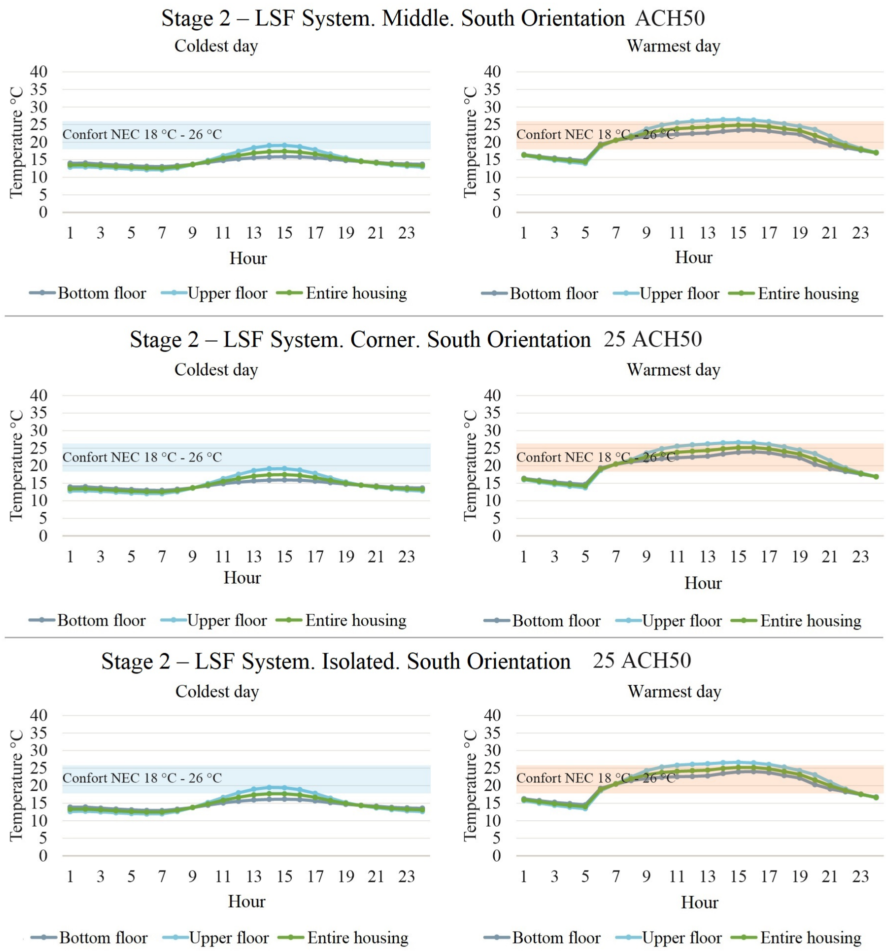
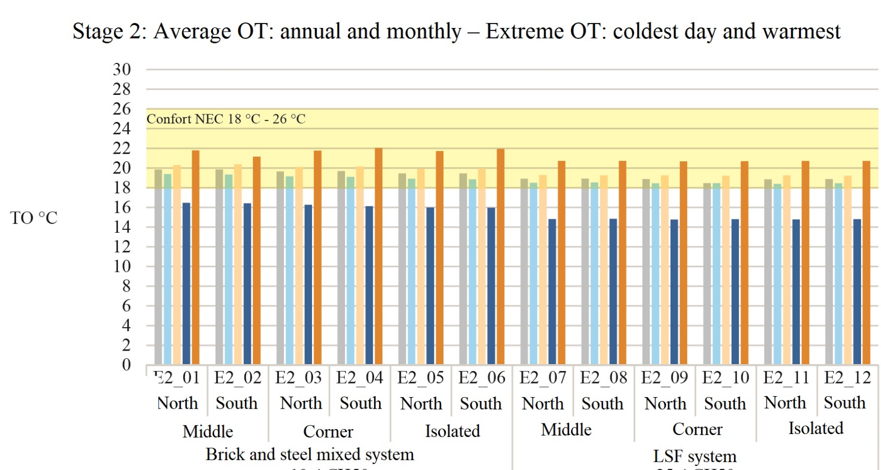


Figure 9. Thermal comparison, LSF system, second stage



	E2_01 North (Middle)	E2_02 South (Middle)	E2_03 North (Corner)	E2_04 South (Corner)	E2_05 North (Isolated)	E2_06 South (Isolated)	E2_07 North (Middle)	E2_08 South (Middle)	E2_09 North (Corner)	E2_10 South (Corner)	E2_11 North (Isolated)	E2_12 South (Isolated)
Annual	19,85	19,85	19,64	19,68	19,44	19,44	18,91	18,92	18,87	18,46	18,85	18,86
Cold month	19,38	19,34	19,15	19,08	18,90	18,84	18,49	18,54	18,44	18,46	18,39	18,44
Warm month	20,27	20,36	20,10	20,14	19,93	19,97	19,27	19,24	19,24	19,19	19,24	19,20
Coldest day	16,47	16,41	16,25	16,13	15,98	15,96	14,81	14,83	14,76	14,79	14,77	14,80
Warmest day	21,78	21,15	21,75	22,02	21,71	21,95	20,71	20,72	20,67	20,69	20,70	20,70

Figure 10. General thermal comparison for the second stage

3.2.1. Analysis of the different inclusions of thermal insulation in the housings with LSF

For the climatic features of the Andean region in Ecuador, the «cold wall» [9] typology is used in the LSF analysis, as it is observed in Figure 11 [9]. This wall typology with the insulation in the internal side retains the heat in the interior in a better way, according to the analysis with THERM. In addition, it is the simplest and the most economical.

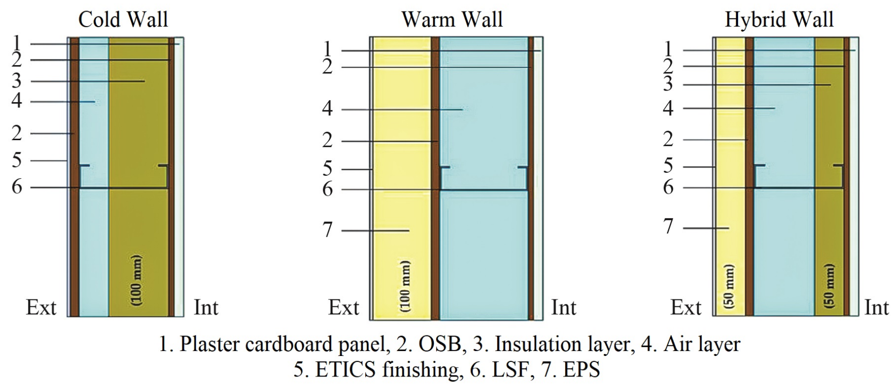


Figure 11. Wall typologies: warm, cold and hybrid

It is also analyzed the incidence of the infiltrations estimated for the constructive topology; according to the construction system, it has been considered an ACH50 of 25, and from it, the consequent thermal performance of the housing. The base housing (A01) shows the worst performance in average. The A02 and A03 cases (A03 interior insulation is recommended by acoustic conditions) are similar. However, the A03 housing implies a more hermetic one, due to a better configuration of the surfaces of the envelope thermally insulated in a more uniform manner. The air chamber produced between the roof and the false ceiling of the upper floor provides better results with respect to the base configuration, considering that these housings are currently not constructed with false ceiling and, much less, with insulation; hence, it is usual the overheating in the presence of direct equatorial irradiation, as well as important thermal losses at night. It is observed that the A04 and A05 cases are critical with respect to the previous ones. This implies that it is necessary insulation in the roof to a larger extent and in the floor to a lesser extent. From the 24 hours of the day, the results are quantified only at the hours that reach the NEC comfort range (18 and 26 °C), as seen in Figure 12.

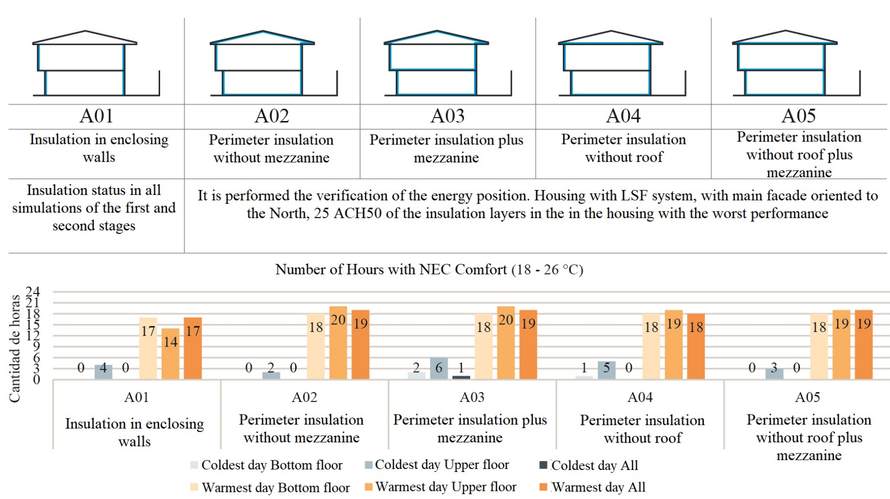


Figure 12. Types of insulation and energy performance in number of comfort hours

3.2.2. Analysis of the energy performance of the different configurations of carpentries by means of THERM

The thermal bridges in the carpentries are also analyzed; the cases to be studied are presented in Table 4. Simulating only the glass panels without the influence of a carpentry, the insulation capacity of the double glass panel (C14) is consistently higher compared to the simple glass panel (C13). Therefore, a window with double glass and air chamber is an improvement. With respect to the carpentry materials, wood or PVC are adequate alternatives with good insulation features, as observed in Figure 13.

Table 4. Simulations of carpentries

N.°	Type	Material	Climatic condition	Configuration of glass panels	Comments
C01	Window	Aluminum	Warm day	simple	Slidigns.
C02			Cold day	double	Profile
C03			Warm day	simple	commercial
C04			Cold day	double	Standard
C05	Window	Wood	Warm day	simple	Sliding.
C06			Cold day	double	Carpentry
C07			Warm day	simple	Handcrafted
C08			Cold day	double	
C09	Window	PVC	Warm day	simple	Sliding.
C10			Cold day	double	Profiles
C11			Warm day	simple	commercial
C12			Cold day	double	Standard
C13	Ninguna	Glass	Indiferente	simple	Exclusive
C14				double	glass panels
C15	Door	Wood	Warm day	simple	Door with
C16			Cold day	simple	simple MDF wood sheet
C17	Door	Steel	Warm day	simple	Door with
C18			Cold day	simple	simple steel plate

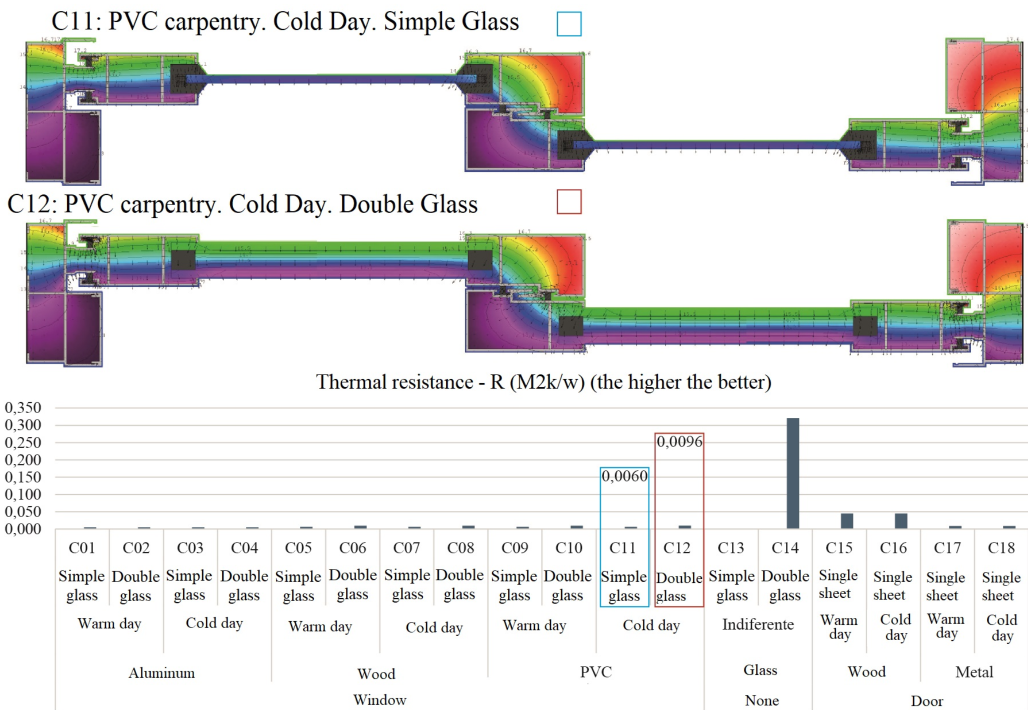


Figure 13. Results of the carpentries in days of extreme cold

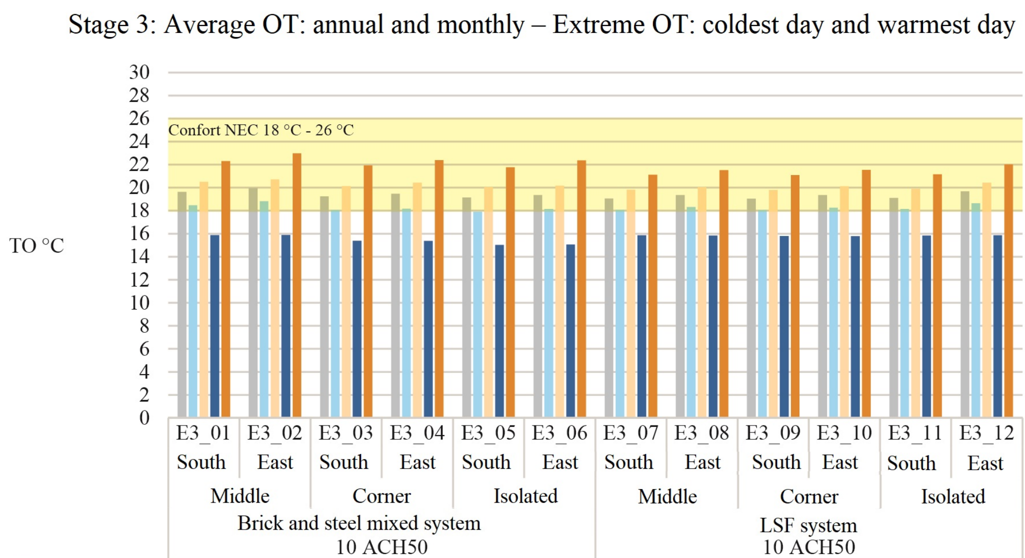
3.3. Third stage: Thermal analysis of a housing with traditional materials vs. a housing with LSF with insulation

At this stage, the indoor temperature under normal use conditions is checked through simulations. In addition, the deployment with the orientations; favorable (east) and unfavorable (south). In the case of LSF with the following variations: Configuration of insulation, minor air infiltrations and carpentries. Table 5 shows the simulations. The housing with LSF uses the simulation solution A03 (perimeter insulation plus mezzanine). Therefore, the level of air infiltrations decreases from 25 to 10 ACH50, data taken from the study by (Madrid; Opazo; Parada, 2012).

Table 5. Conditions for Stage 3 of simulations

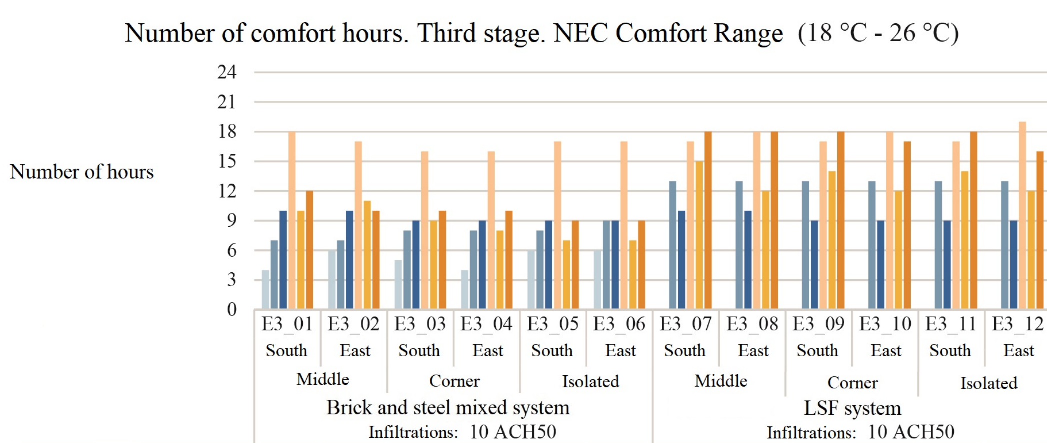
N.°	Construction system		Housing	Orientation of
	Type	Features	typology	front facade
E3_01	Mixed system: brick and steel		Middle	South
E3_02		Traditional		East
E3_03	10 ACH50	masonry	Corner	South
E3_04		housing		East
E3_05	3,7 users		Isolated	South
E3_06	13,31 W/m^2			East
E3_07	LSF System		Middle	South
E3_08		Standard LSF construction.		East
E3_09	10 ACH50	Thermal isolation of the envelope:	Corner	South
E3_10		EPS in Slab, 50 mm stone wool in walls,		East
E3_11	3,7 users	mezzanine and roof.	Isolated	South
E3_12	13,31 W/m^2			East

The general result of every simulation indicates better thermal levels for both construction systems. However, it should be remarked that the thermal gains have been included. In this way, these are the thermal levels of the housing with traditional system for daily use of its occupants. In the case of the LSF system the values are much better, as observed in Figure 14. With respect to the number of comfort hours, Figure 15 shows detailed results.



	E3_01 South	E3_02 East	E3_03 South	E3_04 East	E3_05 South	E3_06 East	E3_07 South	E3_08 East	E3_09 South	E3_10 East	E3_11 South	E3_12 East
Annual	19,62	19,96	19,24	19,45	19,15	19,35	19,04	19,35	19,03	19,34	19,12	19,69
Cold month	18,46	18,80	18,05	18,16	17,90	18,14	18,07	18,32	18,05	18,26	18,15	18,65
Warm month	20,49	20,71	20,12	20,42	20,05	20,15	19,81	20,04	19,80	20,10	19,89	20,43
Coldest day	15,87	15,89	15,38	15,37	15,02	15,05	15,85	15,83	15,80	15,78	15,83	15,85
Warmest day	22,29	22,98	21,93	22,39	21,75	22,36	21,11	21,51	21,09	21,53	21,15	22,00

Figure 14. General thermal comparison for the third stage



	E3_01 South	E3_02 East	E3_03 South	E3_04 East	E3_05 South	E3_06 East	E3_07 South	E3_08 East	E3_09 South	E3_10 East	E3_11 South	E3_12 East
Coldest day Bottom floor	4	6	5	4	6	6	0	0	0	0	0	0
Coldest day Upper floor	7	7	8	8	8	9	13	13	13	13	13	13
Coldest day Both	10	10	9	9	9	9	10	10	9	9	9	9
Warmest day Bottom floor	18	17	16	16	17	17	17	18	17	18	17	19
Warmest day Upper floor	10	11	9	8	7	7	15	12	14	12	14	12
Warmest day Both	12	10	10	10	9	9	18	18	18	17	18	16

Figure 15. Comparison of number of comfort hours for the third stage

A comparison of the thermal levels of this simulation with the previous stage for the most extreme cases leads to the following comments. In the traditional system, the actual one, the housing shows adequate indoor thermal comfort 38 % of the time in a cold day, whereas low temperatures occur at night and early morning. This percentage slightly raises to 42 % for the hottest day, with overheating occurring from 10:00 to 18:00; this is mainly due to the minimum insulation capacity of the roof, as observed in Figure 16.

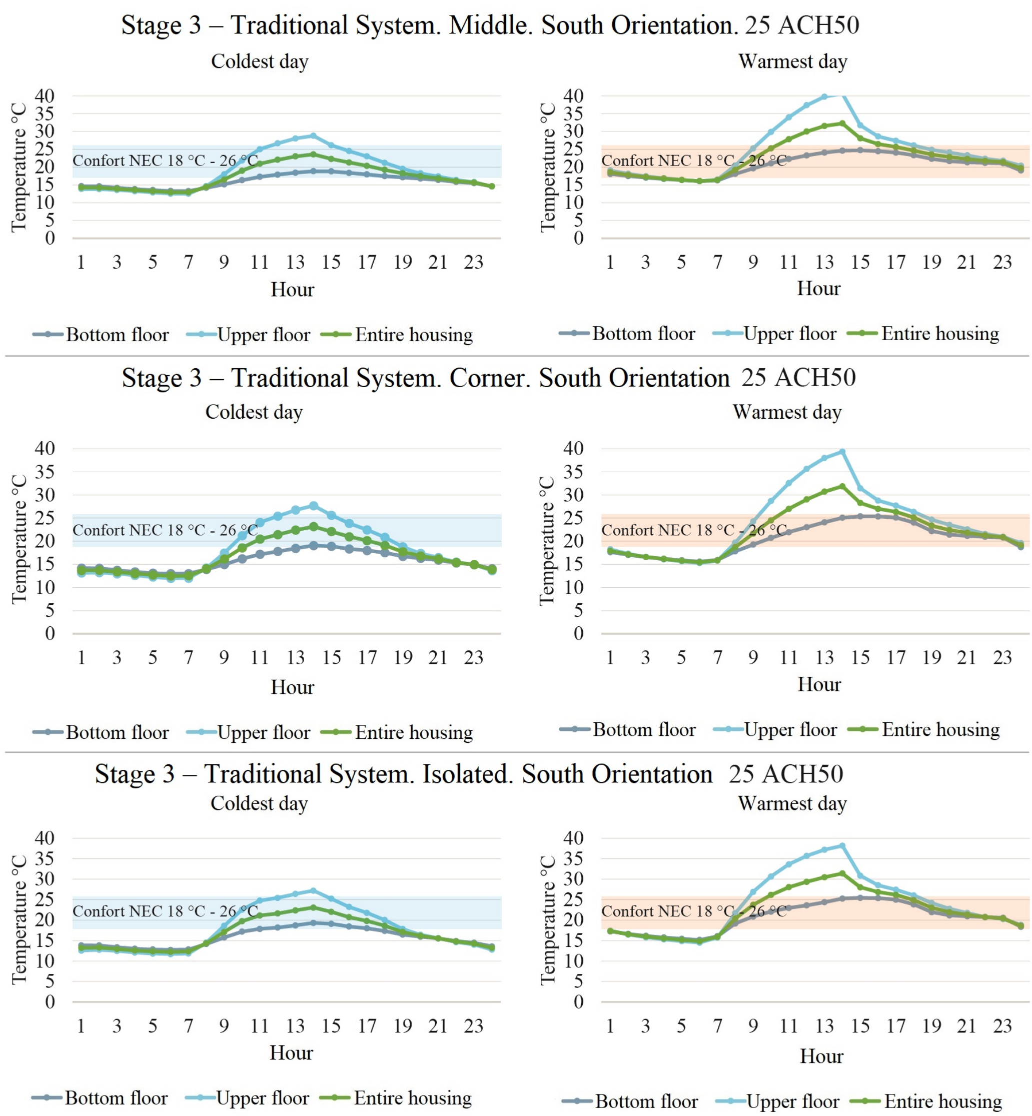


Figure 16. Thermal comparison, traditional system, third stage

In the LSF system, with the standard construction features established in Table 5, during the day the housing reaches indoor thermal comfort 38% of the time, with temperature values between 13.47 °C and 19.52 °C. In the scenario of the day with highest temperature, the housing reaches indoor thermal comfort in 67% of the hours, with a temperature range between 16.53 °C and 26.89 °C. In the coldest and warmest day, the percentage of daily comfort hours practically does not exceed 50% for both construction systems, as it is observed in Figure reffigura17.

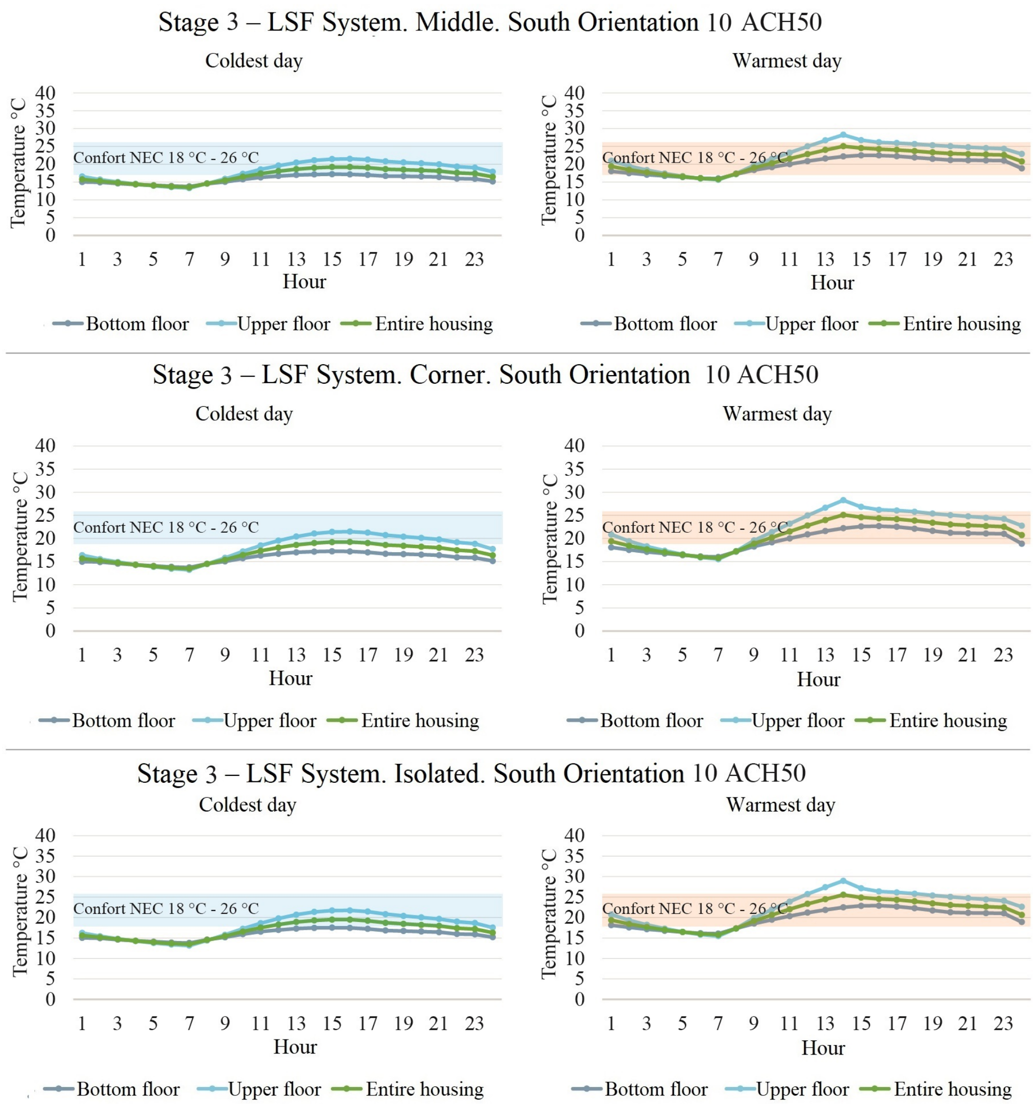


Figure 17. Thermal comparison, LSF system, third stage

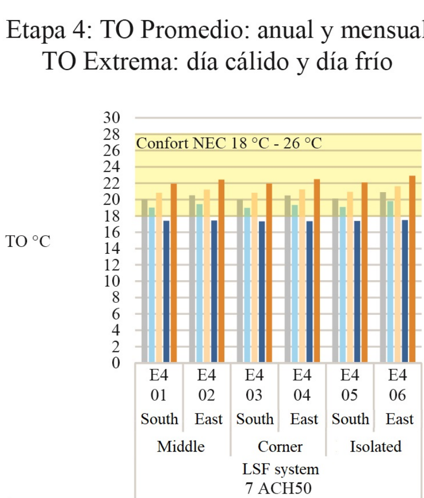
3.4. Fourth stage: Analysis of the housing with LSF with the recommended construction features, with emphasis on constructive quality and air infiltrations

Once it is known the real performance of the reference housing with masonry and steel structure construction system (third stage), the LSF system is analyzed measuring the possibility of increasing the annual comfort hours, adapting the system to improve the constructive quality and the hermeticism of the housing with high performance construction strategies (Table 6). In this stage, an envelope adjustment to reduce infiltrations is considered, assuming to reach 7 ACH50 (Table 6). Previous studies with LSF and wood framework have established a reachable value of 7.47 ACH50 [31]. In parallel, the International Energy Conservation Code (IECC) considers a value of 7 ACH50.

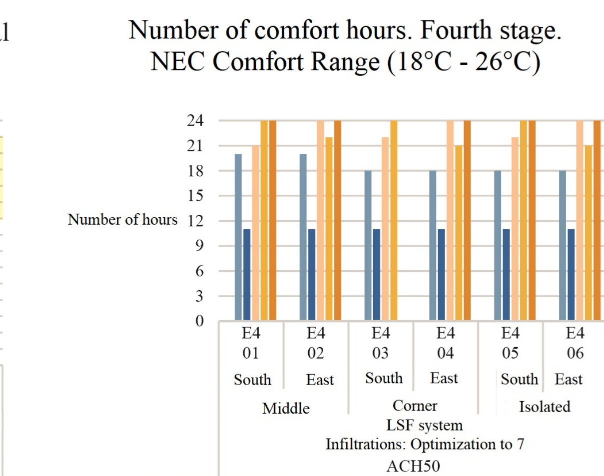
Table 6. Conditions for the stage 4 of simulations

No.	Construction system		Housing	Orientation
	Type + ACH	**Features**	**typology**	**access facade**
E4_01	LSF system	Construction with high	Middle	South
E4_02		insulation. Thermal isolation		East
E4_03	7 ACH50	of the envelope: EPS in Slab,	Corner	South
E4_04		50 mm stone wool in walls,		East
E4_05	3,7 users	mezzanine and roof.	Isolated	South
E4_06	13,31 W/m^2	y cubierta.		East

The results point out that for the coldest day, as shown in Figures 18 and 19, the values of Operating Temperature oscillate between 15.92 and 18.55 °C. The differences between maximum and minimum values are minor. Consequently, it is found that the fluctuations are minor. The increase in comfort hours, with respect to the previous stage, goes from 38 to 46%, with infiltrations of 7 ACH50 with double glass windows. In the analysis of the warmest day, the values of operating temperature are between 20.53 and 25.77 °C. The difference between the maximum and minimum thermal values is considerably smaller than the reference housing. The increase in comfort hours, with respect to the previous stage, goes from 67 to 100%. In the warmest day, an overheating is observed at the time of direct solar incidence, which may be counteracted with natural ventilation due to the lower external temperature.



	E4 01	E4 02	E4 03	E4 04	E4 05	E4 06
Annual	20,05	20,52	20,02	20,49	20,12	20,89
Cold month	19,01	19,44	18,97	19,35	19,07	19,80
Warm month	20,83	21,21	20,82	21,24	20,93	21,62
Coldest day	17,39	17,41	17,32	17,33	17,37	17,48
Warmest day	21,94	22,42	21,95	22,48	22,08	22,92



	E4 01	E4 02	E4 03	E4 04	E4 05	E4 06
Coldest day Bottom floor	0	0	0	0	0	0
Coldest day Upper floor	20	20	18	18	18	18
Coldest day Both	11	11	11	11	11	11
Warmest day Bottom floor	21	24	22	24	22	24
Warmest day Upper floor	24	22	24	21	24	21
Warmest day Both	24	24	0	24	24	24

Figure 18. Comparison of the thermal performance and of the number of comfort hours for the fourth stage

Figure 19 shows the housing with LSF in all orientations, where it is seen that the thermal curve oscillates less throughout the day. The thermal variations are not very pronounced, as it is evidenced in previous stages. With the recommended construction strategies, considering the materials with the purpose of reducing the levels of ACH exchanges, the thermal behavior of the housing is more stable in temperature, without the need of using active heating systems.

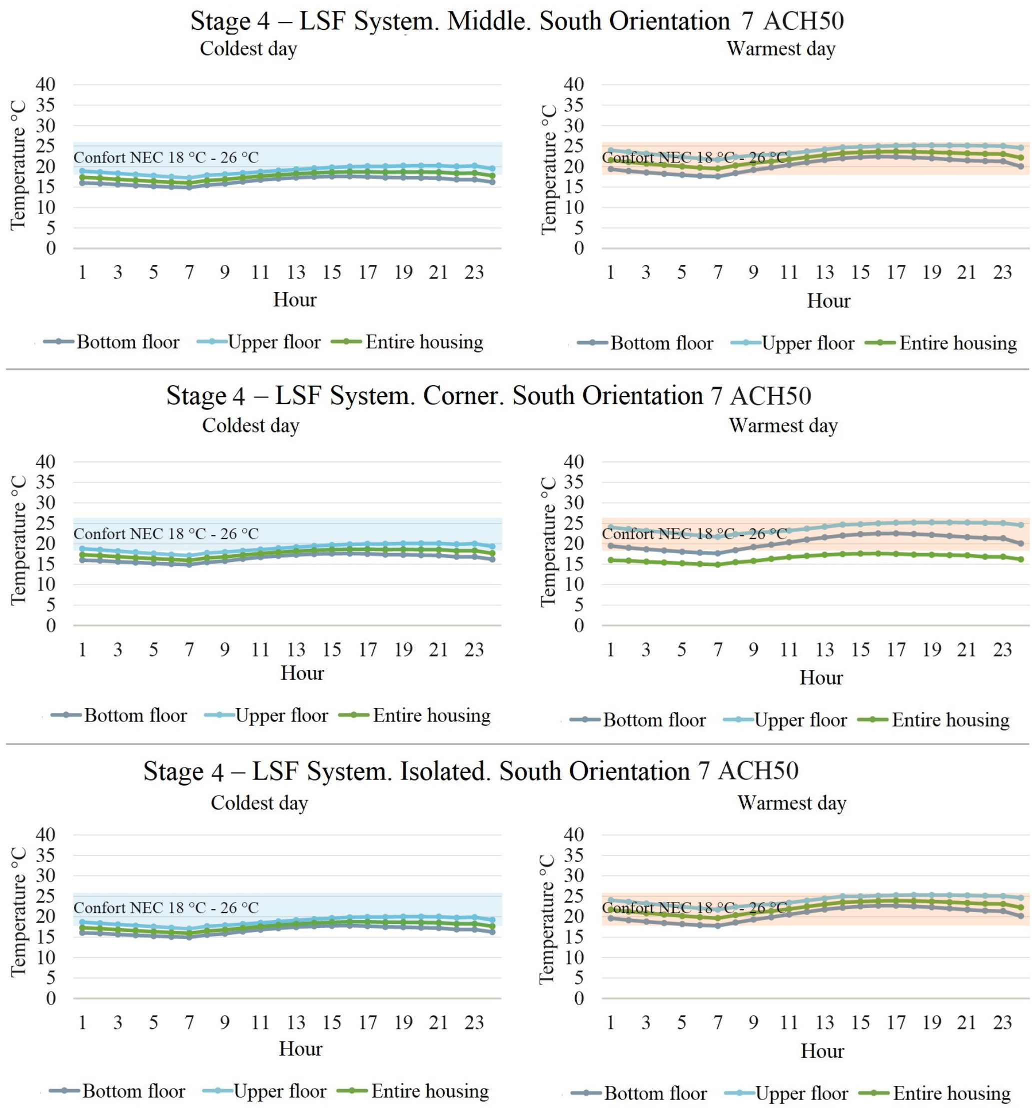


Figure 19. Thermal comparison, LSF system, fourth stage

3.5. Discussion

In the first stage, it is only determined the most favorable and most unfavorable results, with respect to the orientation of the housings. The orientation of the main facade with openings of doors and windows facing towards the east and west is better regarding thermal performance. However, the thermal variation is not considerably smaller in the north-south orientation due to the dimensions of the housing.

In the second stage, the results of unfavorable orientations (north-south) are observed on the reference housing, where indoor thermal comfort is reached in only 27% of hours throughout the year. The housing with LSF, without insulations in subfloor and ceilings, always in the same orientations, reaches indoor thermal comfort 42% of the time. In the third stage, for the housings in their current status the average percentage (under all orientations) of hours in a year in indoor thermal comfort is 51%. This mainly occurs due to the steel structure exposed both internally and externally, and by the important losses in the roof without false ceiling. In addition, doors and windows typically metallic also imply considerable thermal bridges. The housings with LSF and standard optimization strategies to 10 ACH50 improve to 62% the number of comfort hours with respect to the base housing. In stage 4, in Figures 20 and 21, for the housings with LSF with high optimization strategies and infiltrations in 7 ACH50, the percentage of comfort time is 86%.

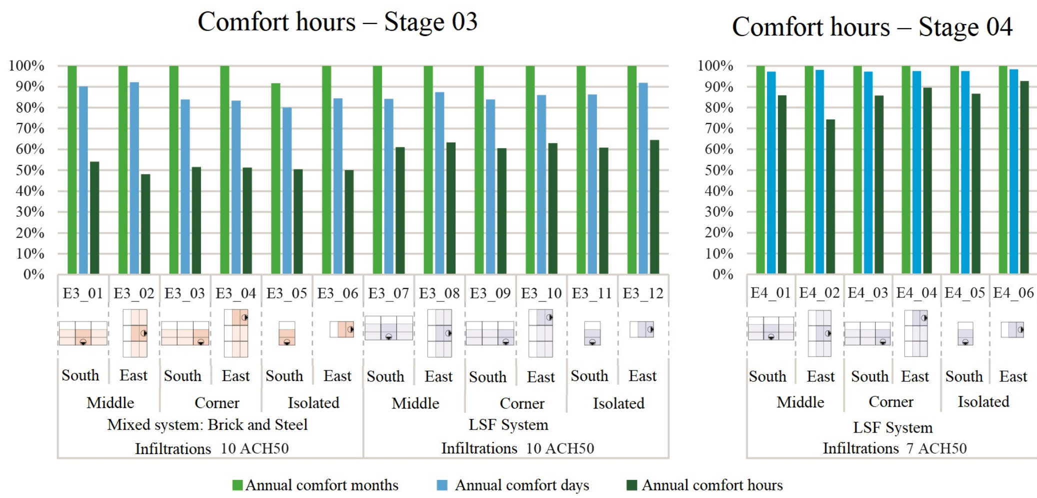


Figure 20. Comparison of the number of comfort hours

The results indicate that the reference housing with traditional construction system has an average minimum temperature of 15.38 °C and an average maximum temperature of 27.68 °C, both out of the NEC comfort range. However, when the housing has an envelope in LSF with standard optimization strategies and with basic features and isolation materials, the average minimum temperature improves slightly to 15.55 °C, without reaching the minimum of the standard, and the average maximum temperature is 26.38 °C, slightly above the maximum of the standard. Finally, for the housing in LSF with high optimization strategies, features recommended by the analysis, the average minimum temperature is 17.19 °C, close to the 18 ºC established by the standard, and temperatures above 26 ºC are not observed. At last, it is found that the parameter with highest thermal incidence is the control of air infiltrations.

Figure 21 shows an average comparative chart of the three housing typologies in a unique monthly, daily and hourly average value. In this way, results are shown as a function of the percentage of average time in which the housings are in comfort. Average values are used, since it was demonstrated in each of the stages that thermal variations of the housing typologies in minimal, without exceeding 1 °C in most cases.

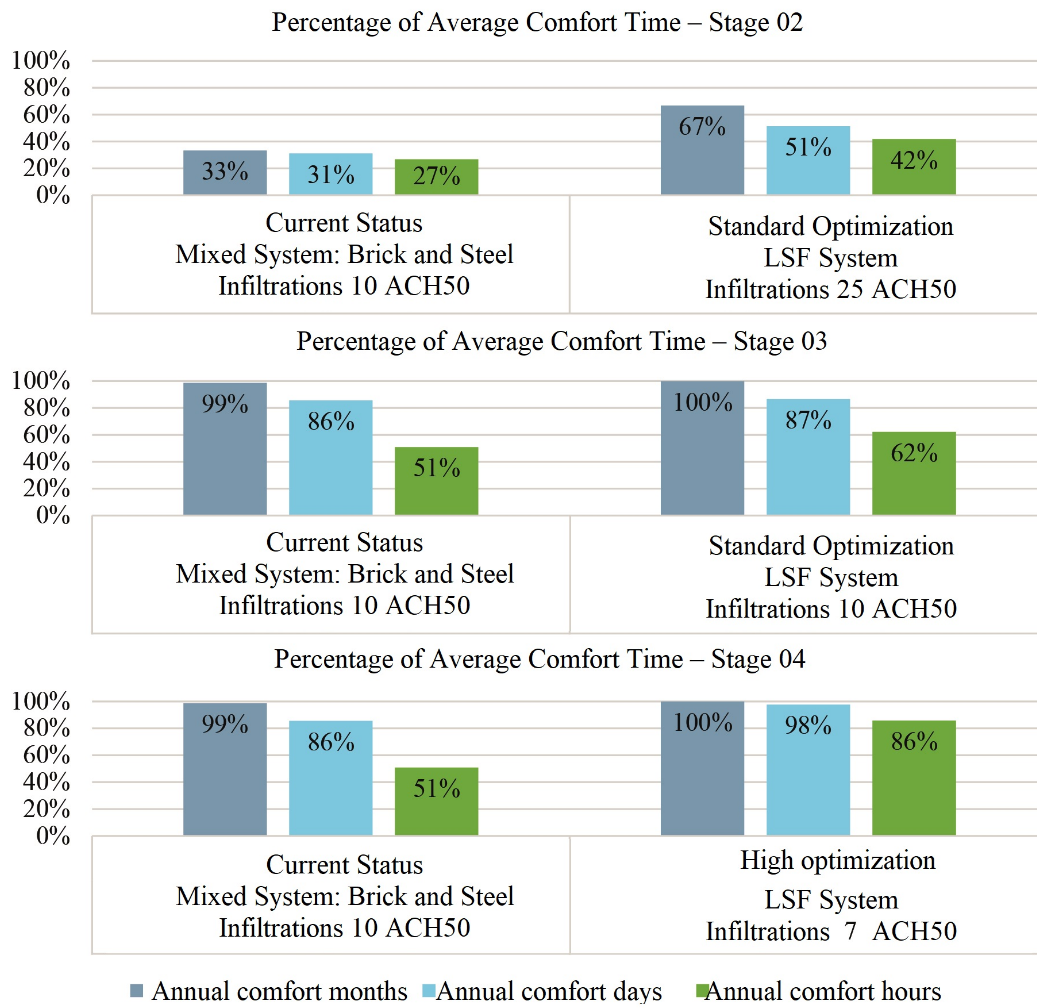


Figure 21. Comparison of the number of comfort hours of all stages

It is evidenced that the dimensions of the LSF section, stated according to the structural analysis, are more than enough to integrate the necessary insulation: 50 mm in stone wool placed between the studs, attached to the external side, leaving an air chamber of 50 mm between the studs, in a cold wall scheme. Then, the other parameters analyzed arranged in decreasing order of importance include air infiltrations, material of carpentries and, to a lesser extent, the orientation. Figure 22 shows a scheme of the housing recommended with the new LSF system for the Andean region.

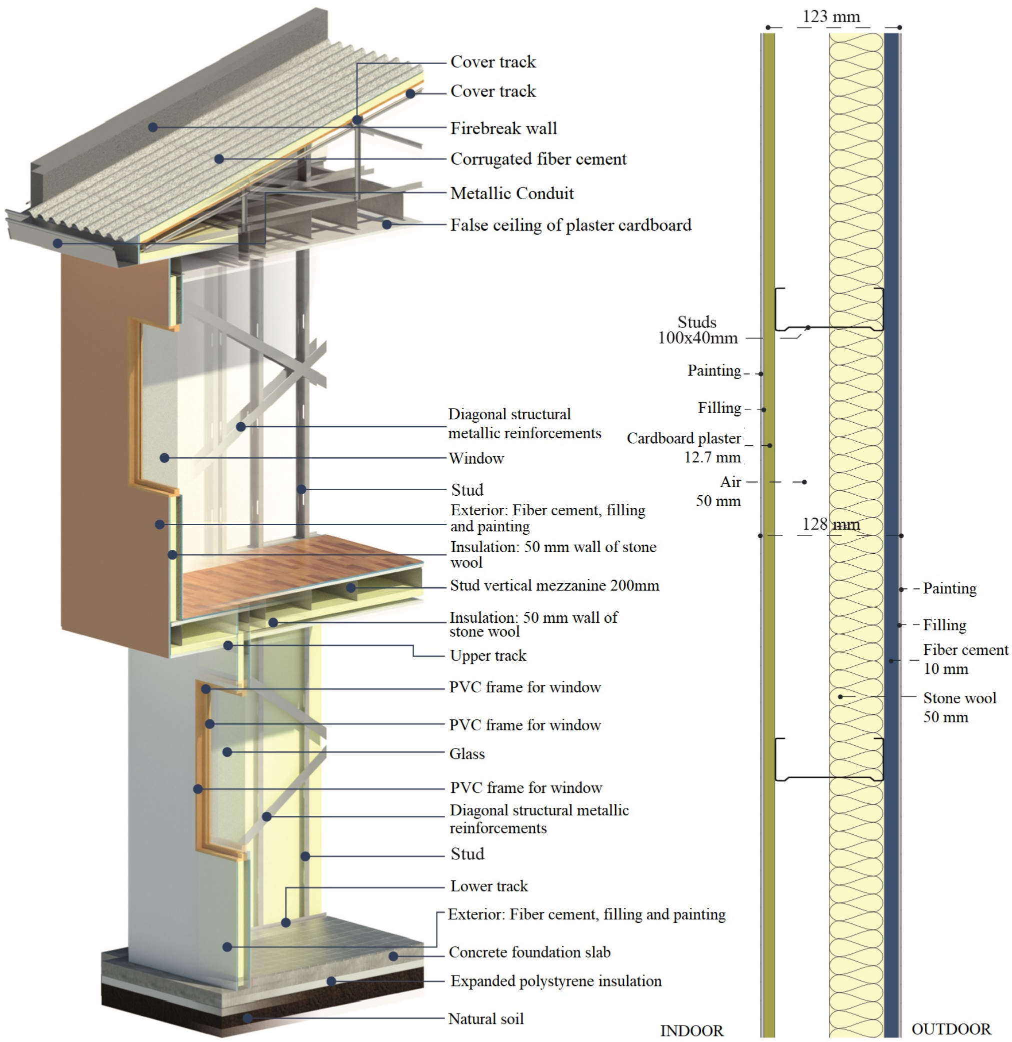


Figure 22. Scheme of the proposal of the housing built with LSF

4. Conclusions

This work carries out an analysis with widely validated simulators, to detect comfort conditions and mismatches in housings when changing and modifying the construction system, as well as the comfort parameters. Once it is analyzed the modification of the envelope from the traditional construction system using steel with brick envelope, it is also analyzed the implications of the modification of the envelope and other parameters such as orientation, infiltration and material of carpentries. Even though these are simulations, it is the fastest way to be able to analyze the different parameters in equal circumstances with the modifications required.

The comfort levels of the housings built with LSF are higher, compared to the reference housing built with the mixed construction system of brick masonry and structure with steel porticoes (traditional construction methodology). With the change in construction system, the number of comfort hours in the housing increases 11%, but a work with hermeticism, change of material in carpentries, insulation in slabs, mezzanines and ceilings, enables to reach 35% more hours within the comfort range. Although the brick block as envelope material has better thermal inertia, the LSF reaches appropriate levels of the envelope, even in the simple configuration in sandwich wall.

The most important variables for environmental performance, according to this study, arranged in decreasing order of thermal influence are: insulation in roof, mezzanine and foundation slab, the results indicate that horizontal insulations increase the percentage of comfort from 42 to 64%. Then, the parameter of air infiltrations through the hermeticism increases thermal comfort from 62 to 86%. Third, considering the housing material in general, together with the type of carpentries, the improvement of one system with respect to the other goes from 51 to 86%. The variables with lower incidence correspond to the deployment and typology of the housings. These factors are due to the configuration and size of the housings, since the dimensions are not big. The orientation, normally a factor of great thermal incidence in other latitudes, for equatorial locations the solar route causes that the irradiation incidence lasts few hours.

The results of the analyses by orientation show that, in average, the indoor temperature is only 1 °C higher in the north – south orientation, and even well-oriented housings receive little direct solar radiation on the facades due to the minimal separation between housings because of the grouping conditions.

With the proposed configuration of materials, it is feasible to build a housing in the city of Cuenca with habitability conditions within the thermal comfort range between 18 °C and 26 °C. Consequently, it is adaptable to various cities in Colombia, Ecuador and Peru that are in equatorial conditions at a height close to 2500 m above sea level. However, for more extreme weather it is necessary to check the envelope adaptability.

The change of materials not only seeks to generate housing that are comfortable for final users, but it also seeks, as indicated by sources consulted, to reduce the environmental and ecological impact generated by the construction industry with handcrafted processes, many of them with no control, avoiding unnecessary wastes and saving resources that are increasingly scarce, before, during and after the construction.

References

[1] V. Arengo Piragine, J. Cruz Breard, and C. Pilar, "Anteproyecto de viviendas sociales con steel framing en corrientes. comparación con sistema húmedo tradicional," *Arquitecno*, no. 15, p. 37, 2020. [Online]. Available: http://dx.doi.org/10.30972/arq.0154386

[2] A. O. Venegas Tomalá, *Evaluación de la energía contenida, emisiones de CO2 y material particulado en la fabricación del ladrillo semimecanizado tochano en Cuenca, a través del análisis de ciclo de vida (ACV).* Universidad de Cuenca, Ecuador, 2018. [Online]. Available: https://bit.ly/2Soq1IU

[3] M. T. Baquero L. and F. Quesada M., "Eficiencia energética en el sector residencial de la ciudad de Cuenca, Ecuador," *Maskana*, vol. 7, no. 2, pp. 147–165, 2016. [Online]. Available: https://doi.org/10.18537/mskn.07.02.11

[4] M. Manzan, E. Zandegiacomo De Zorzi, and W. Lorenzi, "Numerical simulation and sensitivity analysis of a steel framed internal insulation system," *Energy and Buildings*, vol. 158, pp. 1703–1710, 2018. [Online]. Available: https://doi.org/10.1016/j.enbuild.2017.11.069

[5] M. Bernardes, S. G. Nilsson, M. S. Martins, and A. Romanini, "Comparativo econômico da aplicação do sistema light steel framing em habitação de interesse social," *Revista de Arquitetura IMED*, vol. 1, no. 1, pp. 31–40, 2012. [Online]. Available: https://doi.org/10.18256/2318-1109/arqimed.v1n1p31-40

[6] L. M. Lupan, D. L. Manea, and L. M. Moga, "Improving thermal performance of the wall panels using slotted steel stud framing," *Procedia Technology*, vol. 22, pp. 351–357, 2016. [Online]. Available: https://doi.org/10.1016/j.protcy.2016.01.108

[7] INEC. (2017) Encuesta de edificaciones 2017. Instituto Nacional de Estadísticas y Censos del Ecuador. [Online]. Available: https://bit.ly/3NsvnyW

[8] MIDUVI, *NEC-11. Vivienda De Hasta 2 Pisos Con Luces De Hasta 4.0 M.* Ministerio de Desarrollo Urbano y Vivienda. República del Ecuador., 2011. [Online]. Available: https://bit.ly/3HU0uCk

[9] E. Roque and P. Santos, "The effectiveness of thermal insulation in lightweight steel-framed walls with respect to its position," *Buildings*, vol. 7, no. 1, 2017. [Online]. Available: https://doi.org/10.3390/buildings7010013

[10] A. M. Sarmanho Freitas and R. C. Moraes de Crasto, *Steel Framing: Arquitectura.* Instituto Latinoamericano del Fierro y el Acero - ILAFA, 2007. [Online]. Available: https://bit.ly/3QOMYUy

[11] J. L. Lamus Rodríguez, "Análisis de viabilidad económica: sistema constructivo light steel framing en Colombia," Master's thesis, Universidad de los Andes. Colombia, 2015. [Online]. Available: https://bit.ly/3HRQfhU

[12] E. Rodrigues, N. Soares, M. S. Fernandes, A. R. Gaspar, Álvaro Gomes, and J. J. Costa, "An integrated energy performance-driven generative design methodology to foster modular lightweight steel framed dwellings in hot climates," *Energy for Sustainable Development*, vol. 44, pp. 21–36, 2018. [Online]. Available: https://doi.org/10.1016/j.esd.2018.02.006

[13] E. de Angelis and E. Serra, "Light steel-frame walls: Thermal insulation performances and thermal bridges," *Energy Procedia*, vol. 45, pp. 362–371, 2014. [Online]. Available: https://doi.org/10.1016/j.egypro.2014.01.039

[14] B. Schafer, D. Ayhan, J. Leng, P. Liu, D. Padilla-Llano, K. Peterman, M. Stehman, S. Buonopane, M. Eatherton, R. Madsen, B. Manley, C. Moen, N. Nakata, C. Rogers, and

C. Yu, "Seismic response and engineering of cold-formed steel framed buildings," *Structures*, vol. 8, pp. 197–212, 2016. [Online]. Available: https://doi.org/10.1016/j.istruc.2016.05.009

[15] T. Tafsirojjaman, S. Fawzia, D. Thambiratnam, and X. Zhao, "Seismic strengthening of rigid steel frame with cfrp," *Archives of Civil and Mechanical Engineering*, vol. 19, no. 2, pp. 334–347, 2019. [Online]. Available: https://doi.org/10.1016/j.acme.2018.08.007

[16] J. R. da Silva Nogueira, I. J. Apolônio Callejas, and L. Cleonice Durante, "Desempenho de painel de vedação vertical externa em light steel framing composto por placas de madeira mineralizada," *Ambiente Construido*, vol. 18, no. 3, 2018. [Online]. Available: https://doi.org/10.1590/s1678-86212018000300282

[17] F. Bolina, R. Christ, A. Metzler, U. Quinino, and B. Tutikian, "Comparison of the fire resistance of two structural wall systems in light steel framing," *DYNA*, vol. 84, no. 201, pp. 123–128, abr. 2017. [Online]. Available: https://doi.org/10.15446/dyna.v84n201.57487

[18] E. Yandzio, R. M. Lawson, and A. G. J. Way, *Light steel framing in residential construction.* SCI. Silwood Par, Ascot, Berkshire, 2015. [Online]. Available: https://bit.ly/3xXZhoV

[19] P. E. Amador Salomão, A. D. Alves Soares, A. L. P. Lorentz, and L. T. Gonçalves de Paula, "Conventional masonry and light steel framing comparative analysis: a case study in unifammary residence in teófilo otoni, mg," *Research, Society and Development*, vol. 8, no. 9, p. e14891268, Jun. 2019. [Online]. Available: https://doi.org/10.33448/rsd-v8i9.1268

[20] H. OlivieriIvan, I. C. Alves Barbosa, A. C. Da Rocha, A. Denis Granja, and P. S. Pucharelli Fontanini, "A utilização de novos sistemas construtivos para a redução no uso de insumos nos canteiros de obras: Light steel framing," *Ambiente Construido*, vol. 17, no. 4, 2017. [Online]. Available: https://doi.org/10.1590/s1678-86212017000400184

[21] MIDUVI, *Acuerdo Ministerial: Reglamento para validación de tipologías y planes masa para proyectos de vivienda de interés social.* Ministerio de Desarrollo Urbano y vivienda. República del Ecuador, 2019. [Online]. Available: https://bit.ly/3HSg3ul

[22] ——, *Eficiencia energética en edificaciones residenciales NEC-HS-EE.* Ministerio de Desarrollo Urbano y vivienda. República del Ecuador, 2018. [Online]. Available: https://bit.ly/39U5CtD

[23] ——, *Eficiencia energética en la construcción en Ecuador.* Ministerio de Desarrollo Urbano y vivienda. República del Ecuador, 2011. [Online]. Available: https://bit.ly/39QqLoM

[24] Intergovernmental Panel on Climate Change, *Summary for Policymakers.* Cambridge University Press, 2014, ch. Climate Change 2013 – The Physical Science Basis, pp. 1–30. [Online]. Available: https://doi.org/10.1017/CBO9781107415324.004

[25] S. A. Navarrete Boutaud, *Impacto de las infiltraciones de aire en el desempeño energético y térmico de las viviendas.* Universidad de Concepción. Chile, 2016. [Online]. Available: https://bit.ly/3QSwxqg

[26] Design Builder. (2022) Design builder software. [Online]. Available: https://bit.ly/3OnQ8gp

[27] Berkeley Lab. (2022) THERM. Windows and Daylighting. [Online]. Available: https://bit.ly/3HU2iv6

[28] J. Roset Calzada, R. A. Vásquez Paredes, and L. M. Barajas Saldaña, "ús eficient de programes informatics en arquitectura: Designbuilder i Dialux," *JIDA'14. II Jornadas sobre Innovación Docente en Arquitectura*, 2014. [Online]. Available: https://doi.org/10.5821/jida.2014.5027

[29] INEC. (2011) Vii censo de población y vi de vivienda. Instituto Nacional de Estadíticas y Censos. [Online]. Available: https://bit.ly/3br35Ym

[30] H. Madrid, F. Opazo, and O. Parada, "Impacto de las infiltraciones de aire en el desempeño energético y térmico de las viviendas," *Construciión*, 2012. [Online]. Available: https://bit.ly/3yn1Gev

[31] The U.S. Department of Housing and Urban Development Office of Policy Development and Research, *Steel vs. Wood. Cost Comparison. Beaufort Demonstration Homes.* Partnership for Advancing Technology in Housing, 2002. [Online]. Available: https://bit.ly/3ngPhCz