International Journal on Advanced Science Engineering Information Technology

Vol.13 (2023) No. 5
ISSN: 2088-5334

Thermal Comfort in Two Housing Typologies in the Andean Region of Ecuador: Cotopaxi Province

María Augusta Rojas [a,*], Rodrigo Altamirano [a]

[a] *Universidad Indoamérica, Manuela Sáenz y Agramonte, Ambato, 180212, Ecuador*
*Corresponding author: *mrojas4@indoamerica.edu.ec*

***Abstract*— In Ecuador, rural housing in the Andean region has limitations in its implementation and construction, which lacks technical criteria. This is due to scarce research considering the geographical and climatic conditions and the characteristics of construction materials suitable for this type of housing. This study analyzes the thermal comfort of two cases of study located in the Province of Cotopaxi, Ecuador. This location's altitude exceeds 2,900 MASL, and the average temperature ranges between 12°C and -3°C. The selected samples are two predominant single-family housing typologies in the region: the first, with a traditional construction system and the second, with a conventional system. This study has three main parts: in-situ data collection with measurement equipment, user interviews, and software simulations to obtain thermal data. The first phase, data collection and interviews, facilitate the analysis of discomfort hours and operating temperature (OT) of the current state of the housing. These first results allowed the second phase of this study, which is simulation. In this part, modifications of materiality and carpentry were proposed. The results show significant improvements in thermal comfort. Housing 1 increases by 14% of OT, and Housing 2 increases by 23% of O. T. Both study cases show a significant reduction in the discomfort hours. This research's main conclusion is that adequate material management through software simulation can contribute to innovative solutions for thermal comfort. The outgoing results of this study can be used in future housing and interventions in the region.**

***Keywords*— Rural housing; thermal discomfort; housing typologies; software simulation; construction materials.**

Manuscript received 12 Nov. 2022; revised 19 Jul. 2023; accepted 7 Aug. 2023. Date of publication 31 Oct. 2023.

I. INTRODUCTION

The Andean region of Cotopaxi, with an altitude above 2900 MASL, and thermal zone ZT3 with an average temperature of 10°C, has unique conditions to analyze several aspects of the architecture in this region. One of the more important aspects is reaching comfort levels in high-altitude areas. Despite having annual solar radiation between 5.5-6.5 kWh/m2 [1] due to its geographical position, this has not been taken advantage of for thermal comfort. Previous research on thermal comfort with software simulations of dwellings in different climatic zones has motivated this study. Two cases were analyzed with similar rural housing typologies and materials from the parish of Once de Noviembre Cotopaxi. Evaluations were done employing observation, survey, and architectural construction simulation. Rural housing is interactive with its environment. It composes heritage, culture, and tradition; more importantly, it is an emotional and cohesive support for families [2]. Rural housing in some areas of Cotopaxi has prevailed over time, and most of the constructions have used traditional materials. For this reason, this also provides a sustainable identity [3]. However, low winter temperatures in rural areas generate problems related to thermal discomfort for rural housing users[4].

Because of the ongoing discussion of climate change, the study of thermal comfort from architecture has become a relevant topic in the last few years [5]. Thermal comfort is a human sensation that depends on physical, physiological, and psychological factors [6]. Ideal temperature ranges depend on the geographical location to which the characteristics of the house respond [7]. Table 1 shows a summary of standard criteria related to temperature ranges as indicators of thermal comfort.

TABLE I
THERMAL COMFORT INDICATORS ACCORDING TO SEVERAL AUTHORS

Authors	Temperature ranges
Ecuadorian Standard NEC	18-26 °C
Norma NTE-ISO 7730:2005	20-24 °C
ASHRAE (2010)	22.2-26.6 °C

Note: Adapted from various authors [8], [9], [10] Architecture provides spaces with environmental quality. On the other hand, thermal comfort makes a space habitable. Architectural elements contribute thermal and acoustic properties and efficient energy use. [8]. Passive solar housing evaluates the thermal performance provided by building elements [9]. Previous housing studies analyze energy performance as a response to thermal comfort, focusing on climate change [10]. Thermal comfort is related to the appropriate choice of building materials. In this case study, it is important to select materials that benefit warm conditions [11]. The primary variables that define thermal comfort are ambient temperature, radiant temperature, relative humidity, air velocity, metabolic rate, and clothing [12].

The evolution of construction, with the replacement of traditional systems by industrialized techniques, led to the oblivion of passive air conditioning systems, where thermal inertia, ventilation, and shadow control play an important role in architecture, and thus to the massive use of air conditioning systems to create comfort conditions[13]. The main characteristic of rural housing is its diverse use of materials. The traditional local materials are adobe, wood, tiles, and a particular typology of materials manufactured with concrete blocks and metals. The local standards define some referential comfort values. In this case study, the NEC ("Norma Ecuatoriana de la Construcción" Ecuadorian Construction Standard) recommendations are applied [14].

We propose the following hypothesis: Does thermal comfort depend on the materiality and constructive elements used in Andean rural housing? The main objective was to simulate and analyze the thermal comfort in two cases of study in Cotopaxi, and several materials were tested to analyze the materiality as a passive strategy to improve thermal comfort.[15]. In the following sections, the stages of this research are explained: method, survey results, simulations, proposed intervention to the architectural materiality to improve thermal comfort, and discussion and conclusions of this study.[16]

II. Materials and Method

A. Material

In the context of this research, an integral methodological design was applied. This methodology is oriented to the search, analysis, and experimentation of social habitat problems and construction materials. The characteristic of rural housing is its heterogeneous materiality. The predominant materials used in Andean housing are stone, block, and adobe for the facades, concrete, wood, and metal structures, and tiles and zinc for the roofs.

B. Method

The methodological process involves four phases applied in the research of rural Andean housing in Cotopaxi, Ecuador. The study area is defined by its altitude and proximity to the Cotopaxi volcano, one of the highest inhabited areas in Ecuador.

1) Bibliographic review, technical data sheets and cases of study: Bibliographic documentation of thermal comfort in architecture. Design of architectural files. Definition of case studies with experimental design. The control group and factors with independent variable manipulation in housing typology and materiality. The dependent variable is the environmental condition [17], [18].

2) Field survey: Development of data sheets. Definition of study typologies, traditional construction. Case of study measurement with Bosch 35 laser meter, material registration, and development of construction details [19], [20]. Architectural characterization for thermal comfort management in housing.

3) Analysis and simulation: Contribution of previous research [21], [23]. Simulations are developed in the software DesignBuilder 7.0.0.106. Data entry of climate files, materials, and occupancy. Analysis with comfort indicators, software results, material performance, and environmental conditions that determine thermal behavior.

4) Modification and definition phase.: Second simulation with experimental design and strategies for the current state, window opening, and construction improvement. Previous research considers thermal properties [22], [23]. The strategies modify envelopes that contribute to thermal comfort and direct gains for the building.

III. Results and Discussion

Rural Andean housing in the parish of Once de Noviembre, Cotopaxi is selected by its proximity and altitude above 2900 MASL, a high habitable zone in Ecuador. Independent variables define the cases of study T1 and T2. The housing typology has similar architectural composition and traditional construction techniques. To evaluate this parameter, an architectural survey of T1 and T2 housings was carried out by means of illustrations of the current state of the housing. This is the beginning of the research with base models. Autodesk Revit is used to render houses for analysis.

Housing T1 has a conventional construction (see Fig. 1). The building has industrialized materials. The structure is made of concrete and steel. The masonry is made of block and cement mortar. The doors and windows are made of metal and glass. The roof is made of steel and fiber cement.

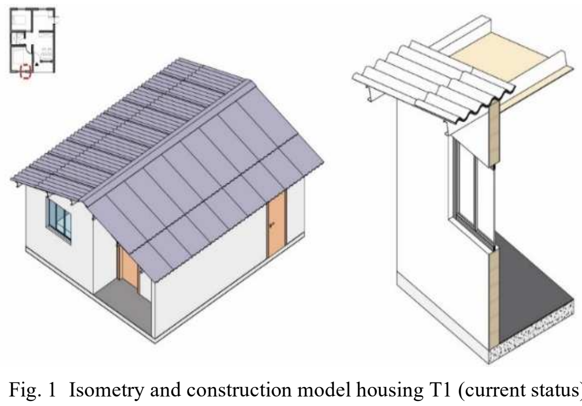


Fig. 1 Isometry and construction model housing T1 (current status)

Housing T2 has traditional construction and local materials (see Fig. 2). The structural elements are made of cyclopean concrete and wood. The masonry is made of adobe with earth mortar. The door and window frames are made of wood, metal, and glass. The roof is made of wood and ceramic tile.

The modeling of T1 and T2 housings was done with the software Revit. Processing and configuration of the architectural materiality was done (see Fig. 1 y 2). The meteorological information from M0004 station [24] was used to setup the simulation. The first simulation was done to obtain comfort levels of the current state.

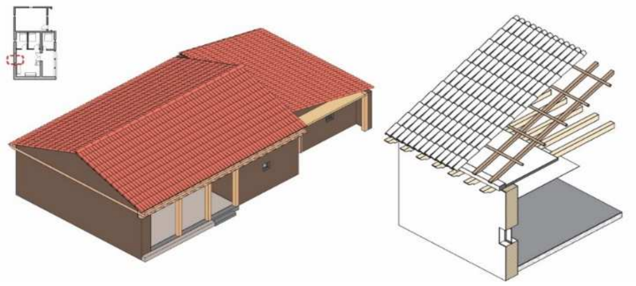
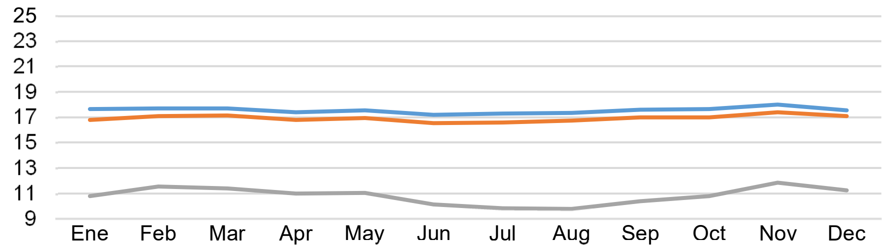


Fig. 2 Isometry and construction model housing T2 (current status).

Figure 3 shows the simulations of housings T1 and T2. The annual outdoor temperature is the gray line. The internal operating temperature (OT) is the average of the internal air and radiant temperatures. The OT of T1 is the blue line, and T2 is the orange line. Both lines are approximated at 17°C. An analysis shows that the critical temperature is in August for both cases. For this reason, a more detailed study is being done for this month.

Figure 4 shows the simulation of housings T1 and T2 for August with an external temperature of 9.79°C. It shows the discomfort hours and internal operating temperature. The software also provides a CFD analysis (Computational Fluid Dynamics) of the air inside the housing. It provides the air temperature ranges (see Fig. 5). Air infiltrated through facade openings is represented by a blue color. This is because external air has a lower temperature than air inside the house.



	Ene	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
O.T. HT1	17,62	17,7	17,7	17,38	17,52	17,21	17,29	17,35	17,59	17,64	18	17,53
O.T. HT2	16,78	17,1	17,13	16,81	16,94	16,54	16,58	16,71	16,97	16,99	17,43	17,11
Outside T.	10,77	11,54	11,39	11,01	11,06	10,11	9,83	9,79	10,39	10,76	11,86	11,26
T. NEC 18 to 26°C												

Fig. 3 Outdoor and indoor operating temperature in housings T1 and T2, status

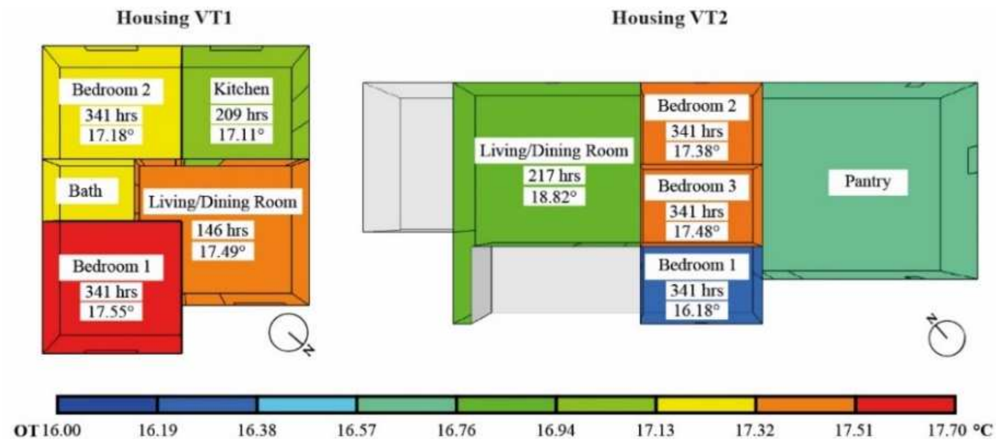


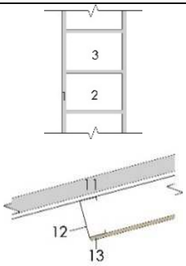
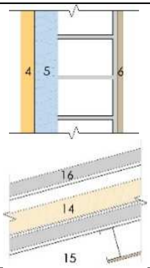
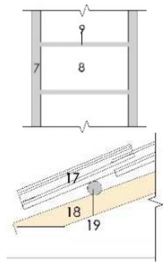
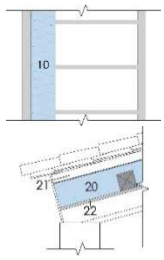
Fig. 4 Discomfort hours and OT in housing T1 and T2 current condition in August

Fig. 5 CFD analysis graphs in housing T1 and T2 status

The next step is to analyze the modification to the materiality of the Andean housing. The proposed improvements are simulated to evaluate the changes in the comfort conditions of living spaces. Passive building strategies consider meteorological data, psychometric charts, natural ventilation, and windows and facade layer modification.

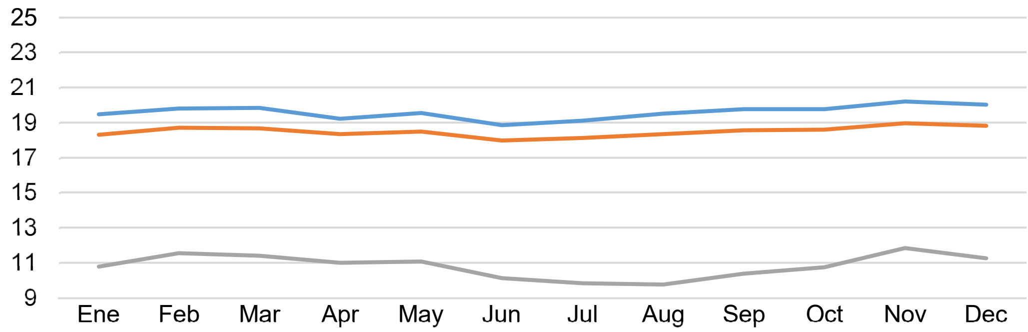
The modified state reinforces the materiality of facades and increases insulation with low environmental impact. Insulation and finishing materials are local, such as layers of sheep wool, mortars, plaster, and wood boards (See Table 2).

TABLE II
CURRENT STATE OF THE HOUSING AND PROPOSED INTERVENTIONS

Housing	Facade Wall/ Roof Current	 Modified
HT1		
HT2		

Note: Data obtained from software simulations. 1. Sand-cement mortar plaster, 2-3. Concrete block, 4. Plaster, sponging and painting, 5. Insulation, 6. Finishing board, 7. Lime plaster, 8. Adobe block, 9. Adobe mortar, 10. Facade insulation, 11. Fiber cement sheet, 12. Steel profile, 13. Wooden board, 14. Roof insulation, 15. False sky, 16. Roofing sheet, 17. Handmade roof tile, 18. Beam, 19. Wooden strips, 20. Roof insulation, 21. Ceramic tile, 22. Modified false sky.

The second simulation phase is done to improve the materiality and obtain changes in the operating temperature inside housings T1 and T2 (see Fig. 6).



	Ene	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
O.T. HT1-M	19,47	19,8	19,84	19,23	19,53	18,85	19,09	19,49	19,78	19,76	20,2	20,03
O.T. HT2-M	18,32	18,71	18,67	18,34	18,47	18	18,11	18,35	18,54	18,58	18,98	18,82
Outside Temperature	10,77	11,54	11,39	11,01	11,06	10,11	9,83	9,79	10,39	10,76	11,86	11,26
T. ranges NEC												

Fig. 6 Outdoor and indoor operating temperature of housings T1 and T2 modified status.

Figure 7 shows the simulation of the discomfort hours in August for the modified status. It is also shown the internal operating temperature. The operating temperature has effectively increased, and the discomfort hours have decreased.

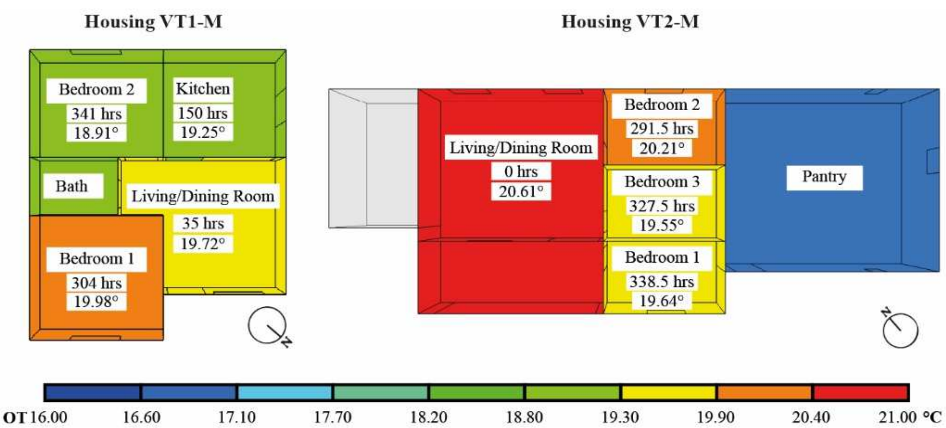


Fig. 7 Discomfort hours and OT in housing T1 and T2 modified state in August.

The summary of the current and improved statuses shows a notable change in operating temperature and discomfort hours. Housing T1. The results obtained indicate an improvement in living spaces. These spaces fall within the reference temperature ranges determined by the NEC [14]. Furthermore, the hours of discomfort decreased significantly (See Table 3).

TABLE III
SUMMARY OF OT AND DISCOMFORT HOURS OF HOUSING T1 AND T1M

Room	Operating Temperature			Discomfort hours		
	T1	T1M	Increase	T1	T1M	Decrease
Living room	17.49	19.72	2.23 (13%)	146	34.5	11.23 (23%)
Bedroom 1	17.55	19.98	2.43 (14%)	341	303.5	38 (12%)
Bedroom 2	17.18	18.91	1.73 (10%)	341	341.0	0.5 (0.15%)

Note. Data obtained from software simulations. Temperature in °C

Housing T2. The proposal improves the living spaces. The operating temperature in the living spaces has increased, and they are acceptable according to NEC standards [14]. The decrease in the number of hours of discomfort is also significant (See Table 4).

TABLE IV
SUMMARY OF OT AND DISCOMFORT HOURS OF HOUSING T2 AND T2M

Room	Operating Temperature			Discomfort hours		
	T2	T2M	Increase	T2	T2M	Decrease
Living room	16.82	20.61	3.79 (23%)	217	216.5	0.5 (0.2%)
Bedroom 1	16.18	19.64	3.46 (21%)	341	338.5	2.5 (1%)
Bedroom 2	17.38	20.21	2.83 (16%)	341	291.5	49.5 (17%)
Bedroom 3	17.48	19.55	2.07 (12%)	341	327.5	13.5 (4%)

Note. Data obtained from software simulations. Temperature in °C

IV. CONCLUSION

In this study, two types of houses were analyzed in the Andean region of Ecuador. Simulations were carried out to determine how the operating temperature and discomfort hours change due to different construction materials. The findings show that the proposed materiality provides thermal comfort within reference parameters and provides habitability conditions. Previous studies [21] established the improvement of dwellings meeting local standards with comfort conditions without using artificial means for the intervention. The reason for these comfort gains is the improvement of envelopes and enlargement of windows.

Considering thermal insulation construction techniques [22], we propose local insulation and minimum environmental impact, in addition to thermal improvements, by applying facade plasters that have been tested with good performance [3]. Temperatures below 12 ºC in Cotopaxi and the local architecture show that the houses do not comply with regulations and thermal comfort requirements. Buildings in cold areas require thermal insulation. From the results, we recommend that local architectures develop construction techniques with better thermal conditions or better application of heating strategies.

The proposed models achieved temperature ranges determined by the NEC between 18 to 26 °C. The proposal helps to increase the operating temperatures for the house's living spaces. We obtained a referential increase of 3.79 °C (23%) and a significant reduction in discomfort hours. It is concluded that the T2 house has better characteristics because it increases the operating temperature by 23% compared to the T1 house, which reaches an increment of 14%. Despite the good thermal characteristics of traditional construction materials, the results show that the traditional house does not have good thermal comfort. This study had equipment limitations for thermal data validation. However, the simulations showed changes to the current state of the T1 and T2 dwellings.

Finally, this study ratifies that housing should consider thermal comfort and habitability conditions. It can be designed, reflected, and analyzed prior to its construction, being possibly a numerical validation of the project. The information derived from the study of rural housing in the Andean region will support future designs that respond to bioclimatic considerations. Future studies to continue the development of the field of study are the thermal performance of building materials and the analysis of building age and thermal behavior.

REFERENCES

[1] C. Conelec, "Atlas Solar del Ecuador con fines de generación eléctrica," *Obtenido de http://energia. org. ec/cie/wp-content/uploads/2017/09*, 2008.

[2] C. S. Quintanar and E. O. J. Rosas, "La vivienda rural. Su complejidad y estudio desde diversas disciplinas.," *Revista Luna Azul*, no. 30, pp. 174–196, 2010.

[3] G. A. Abanto, M. Karkri, and G. Lefebvre, "Thermal properties of adobe employed in Peruvian rural" *Journal of Sustainable Built Environment*, vol. 4, no. 2, pp. 348–358, 2015, doi:. 10.1016/j.cscm.2017.02.001.

[4] M. Philokyprou and A. Michael, "Environmental sustainability in the conservation of vernacular architecture. The case of rural and urban traditional settlements in Cyprus" *International Journal of Architectural Heritage*, vol. 15, no. 11, pp. 1741–1763, 2021, doi:. 10.1080/15583058.2020.1719235.

[5] R. F. Rupp, N. G. Vásquez, and R. Lamberts, "A review of human thermal comfort in the built environment," *Energy Build*, vol. 105, pp. 178–205, 2015.

[6] R. Lamberts, A. A. Xavier, S. Goulart, and R. de Vecchi, "Conforto e stress térmico," *LabEEE, UFSC*, 2011.

[7] C. F. Espinosa Cancino and A. Cortés Fuentes, "Confort higro-térmico en vivienda social y la percepción del habitante," *Revista Invi*, vol. 30, no. 85, pp. 227–242, 2015, doi:10.4067/S0718-83582015000300008

[8] R. D'Alençon, *Acondicionamientos: Arquitectura y técnica*. Ediciones ARQ, 2008.

[9] A. F. Condori, "Construccion de una vivienda solar en base a las propiedades termofisicas y evaluación experimental de su confort térmico en Ilave," *Revista Investigaciones Altoandinas*, vol. 16, no. 1, pp. 177–186, 2014, doi:10.18271/ria.2014.101.

[10] E. Delgado-Gutierrez, J. Canivell, D. Bienvenido-Huertas, C. Rubio-Bellido, and D. Delgado-Gutierrez, "Ecuadorian social housing: energetic analysis based on thermal comfort to reduce energy poverty," in *Energy Poverty Alleviation: New Approaches and Contexts*, Springer, 2022, pp. 209–224, doi: 10.1007/978-3-030-91084-6_9

[11] J. M. Thomas, S. Algohary, F. Hammad, and W. O. Soboyejo, "Materials selection for thermal comfort in passive solar buildings," *J Mater Sci*, vol. 41, pp. 6897–6907, 2006, doi:10.1007/s10853-006-0222-5

[12] J. Raish, "Thermal comfort: Designing for people," *Lang, W., McClain, A., Eds*, 2003.

[13] J. Monjo Carrió, "La evolución de los sistemas constructivos en la edificación. Procedimientos para su industrialización," 2005, doi: 10.3989/ic.2005.v57.i499-500.481

[14] M. F. Vásquez Unda, “Análisis investigativo del cumplimiento de la Norma Ecuatoriana de la Construcción en la industria de la construcción del Distrito Metropolitano de Quito,” Quito, 2019., 2019.

[15] Instituto Ecuatoriano de Normalización, Norma Técnica Ecuatoriana NTE INEN-ISO 7730, Quito, 2014.

[16] R. of Heating and A.-C. Engineers, *Thermal Environmental Conditions for Human Occupancy: ANSI/ASHRAE Standard 55-2013 (supersedes ANSI/ASHRAE Standard 55-2010).* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2010.

[17] R. H. Sampieri, *Metodologia de la investigación: las rutas cuantitativa, cualitativa y mixta*. McGraw Hill México, 2018.

[18] E. A. Tena Suck, I. T. Plaza, and others, “Manual de investigación experimental: elaboración de tesis/por Edgar Antonio Tena Suck y Berbardo Turnbull Plaza.” México, D.F.: Plaza y Valdés, S.A. de C.V, 2001.

[19] J. Cuni, M. Miranda, and A. Pérez, “Dossier de Productos,” *Tectonica-Monografias de Arquitectura Tecnologia y Construccion*, no. 39, p. 87, 2012.

[20] J. Cuni and M. Miranda, “Dossier de productos.,” *Tectónica: monografias de arquitectura, tecnologia y construcción*, no. 16, p. 89, 2003.

[21] C. Rubio-Bellido, A. Pérez-Fargallo, J. A. Pulido-Arcas, and M. Trebilcock, “Application of adaptive comfort behaviors in Chilean social housing standards under the influence of climate change,” in *Building Simulation*, 2017, pp. 933–947, doi: 10.1007/s12273-017-0385-9.

[22] J. R. Molina, G. Lefebvre, R. Espinoza, M. Horn, and M. M. Gómez, “Bioclimatic approach for rural dwellings in the cold, high Andean region: A case study of a Peruvian house,” *Energy Build*, vol. 231, p. 110605, 2021, doi:. 10.1016/j.enbuild.2020.110605.

[23] C. of the European Communities, K. Alder, C. Eriksson, A. Faist, and N. Morel, “Energy balance and thermal comfort in passive solar housing,” in *First EC Conference on Solar Heating: Proceedings of the International Conference held at Amsterdam, April 30-May 4, 1984*, 1984, pp. 386–390.

[24] L. A. Mena Molina, “Análisis del comportamiento de la precipitación y temperatura según registros meteorológicos de la estación meteorológica Rumipamba en los últimos 30 años y el primer año de pandemia. Cotopaxi–2021.,” Ecuador: Latacunga: Universidad Técnica de Cotopaxi (UTC), 2022.