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Indoor environment of a building under the conditions of tropical climate

Внутренняя среда жилых помещений в условиях тропического климата

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Ключевые слова: энергоэффективность; теплоустойчивость; климат в помещении; ограждающие конструкции; строительные материалы; изменение температуры

Abstract. This paper is focused on having a different approach to energy efficiency and the way it is employed in industry. It considers the real case of Latin-America where normal temperature during day drastically changes from 0 to 25 degrees. Such temperature variation affects the indoor climate and its comfort. Therefore, one of the important tasks in construction of such regions is the correct choice of building materials for the enclosing structures. This article studies the typical construction materials in Colombia by analyzing its energy behavior. Temperature experiments are made for typical reinforced concrete and bricks. As a result of the experiment, it has been obtained that enclosing structures consisting of bicks are more stable to sudden changes in outside air temperature, suggesting it as the most appropriate solution for such climatic conditions.

Аннотация. Данная статья посвящена энергоэффективности в строительной индустрии. Рассматривается существующие жилые здания Латинской Америки, где температура воздуха в течении дня может резко измениться с 0 до 25 градусов Цельсия. Такие температурные колебания влияют на внутренний климат помещений и его комфорт. Поэтому одной из важных задач при строительстве жилых зданий в регионах с таким климатом является правильный выбор строительных материалов для ограждающих конструкций. В статье исследуются типичные строительные материалы в Колумбии с учетом анализа их энергетического поведения. Проводятся температурные эксперименты для таких материалов как железобетон и кирпич. В результате эксперимента было получено, что ограждающие конструкции, состоящие из полнотелого кирпича, более устойчивы к резким изменениям температуры наружного воздуха, что является наиболее подходящим решением для таких климатических условий.

Introduction

Most of the studies analyse conditions of materials for keeping warm the inside facilities because of the extremely low temperatures they must deal with. Furthermore there is comparable little literature about Latin-America and its warm environments. There is a need of analysing materials which can improve living conditions [3]; studies have confirmed the correlation between temperature and human working performance. Moreover, is a priority for governments to give the best possible settings to citizens protecting them from potential illness due to unbearable working and living conditions, all this translates into guaranteeing good Social Health. Typical tropical climates may change in a drastic manner, this makes daily living uncomfortable to citizens which must deal with hot temperatures and cold ones in the same day. In Latin-America most of the principal cities must deal with relatively high temperatures [1, 2]. Colombia is not the exception having cities with more than 25 °C all year long; moreover must be considered the opposite conditions whit cities that have medium-low temperatures which can, inclusively, drop down to 0 °C.

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The climate of Colombia is dominated by its geographical conditions more than stationary regimes, this is due to the proximity to the Equator line (Latitude 0°). Located in the tropic is usual to have a different range of temperatures and conditions; of high influence is the mountain range which divides the country and defines the climatic parameters. In very short distances climatic conditions can change because of the topographic characteristics of each zone. High pressure zones in the sub-tropics and the low pressure in the equatorial line lead to massive air currents. These are located in the called Convergence Inter-tropical Line. Bogotá (the capital city) is located in the mountain ridge, which has average temperatures during the day of 15 °C; during the night temperatures oscillates around 5 °C dropping down to 0 °C. In contrast to Bogotá, almost all the other main cities must deal with high temperatures as shown in the following table.

Table 1. Average temperatures in the main cities of Colombia

Main Cities in Colombia	Average Temperature (C°)	Highest Temp (C°)	Lowest Temp (C°)	Delta Temp (C°)
CARTAGENA	28	32	22	10
SANTA MARTA	27	35	20	15
BOGOTÁ	14	21	0	21
MEDELLIN	21	28	17	11
TUNJA	13	19	1	18
PEREIRA	22	26	18	8
VILLAVICENCIO	25	32	20	12
NEIVA	28	35	23	12
POPAYAN	19	24	12	12
PASTO	13	18	2	16
ARMENIA	23	28	15	13
BUCARAMANGA	23	29	19	10
CALI	24	31	18	13

Climatic conditions demand solutions to deal with high temperatures; for special cases as Neiva it is extremely hot (28 °C). Although low temperatures, in Bogotá and Tunja is necessary to apply a solution which give comfort and good design to residences and commercial structures.

More than 30 countries laying in the tropic suffer the same problematic identified in this article, extreme temperature changes during short periods of time. In this way the purpose is to deliver accurate results for complementing the efforts of improving indoor environments in all the different structures. Moreover the objective is to give values that help understand the differences between both materials, more deeply, is to give suggestions of the predominance of the best one which gather together the best solution to the characteristics of the climatic conditions described.

Typical construction in Colombia

At the present time in Colombia there are mainly 2 types of technologies used in the construction of new buildings and houses:

1) Reinforced concrete structures (Fig. 1);

2) Brick structures (Fig. 2).

Figure 1. Typical concrete structure

Figure 2. Construction with bricks

Bricks / masonry are the typical and most used material in Colombia. It is in direct contact with the outside with no layers that divide it from the inside [4]. The reason of the highly use of bricks in Bogotá is what is called the “Bricks Culture” which has made the identity of the city; new bold and adventurous designs make the city unique over others, furthermore with international recognition [5]. Constructions made of bricks are much more expensive than those in concrete, but what makes the difference is the low prices of labour or workforce. This makes an advantage for allowing big projects to be made out of bricks (Fig. 2). The main reasons for positioning this material in Bogotá was that during the 50´s the best recognized architects used massively bricks for almost all projects, with new designs and textures they gave the actual prestige to the material. Another reason is the abundance of production factories among the country. On the other hand, concrete is mostly used for simple designs and fast construction, moreover concrete is much cheaper than bricks [6].

The indoor climate is one of the main tasks during the construction of residential buildings [7–12]. Therefore, a special attention should be paid to the selection of materials. Although heat moisture conditions of the building envelope have been studied actively during a long time in construction; the final answer for which material is the best one doesn't exist [13–15].

The motivation of this article is under the perspective of having a study to real conditions in a country with similar weather as many southern cities in Russia. In this way is possible to link a global approach under the scope of improving living conditions for people. Furthermore is a tool for governmental entities helping them to understand real problematic and give real solutions and accurate conclusions.

Goal and objectives.

Most of the building in Colombia do not use a heating system or insulation on walls and roofs. Therefore, the main strategy to heat building deals with proper material selection and the orientation of the building. For this purpose the following objectives have been set:

- Detection of the thermal characteristics of materials;

- Analyzing the thermal stability of the most common enclosing structures for non-periodic regime;

- Comparison experimental data and formulation of recommendations for material selections.

Methods and Materials.

For this study were selected two types of the materials used in Colombian construction (Table 2). In laboratory materials were compared for showing appropriate conclusions based on the results. Following are the characteristics of both in accordance to its energy efficiency.

Table 2. Thermal characteristics of materials

№	Material	Thickness δ, [m]	Coefficient of thermal conductivity λ, [W/(m·°C)]	Specific heat c_p, [J/(kg·°C)]	Density ρ, [kg/m^3]	Coefficient of thermal absorption β, [J/($\sqrt{s}$·m^2·°C)]
1	Reinforced concrete	0.12	1.7	840	2500	1889.44
2	Ceramic brick	0.12	0.64	880	1600	949.27

The experiment consists on simulating the real conditions of typical structures in tropical climates, it is by drastic temperature changes in few hours during one same day. It has built a box (imitation of a closed room) for both materials: bricks and reinforced concrete simulating the indoor conditions. Installing the appropriate sensors and equipment inside it is the way to be in accordance with real characteristics of buildings [16, 17]. In addition, for both surfaces (up and down) it was sealed with thermic isolation for simulating roof and floor of a typical internal environment. The initial temperature of the air inside the chamber is 25 °C, followed by a drastic drop down to 0°C and then up to the initial temperature. These is to go in accordance to typical behaviors because in the early morning temperature is 0 °C and proportionally increased until the highest 25 °C during midday. Temperature inside the "box" is registered and collected for both specimens, brick and concrete. In this way is able to compare the behavior which really apply in real life conditions [6, 18] for giving future conclusions about the most appropriate material which guarantees comfort. As explained before and in accordance to the aim of this article, the idea is to simulate with all possible details all conditions of environments in similar climatic conditions tendencies.

Initial data

Consider the periodic regime of a reinforced concrete structure.

It consists of the following: a wooden board, a heater, a reinforced concrete sample. It is represented in Figure 3.

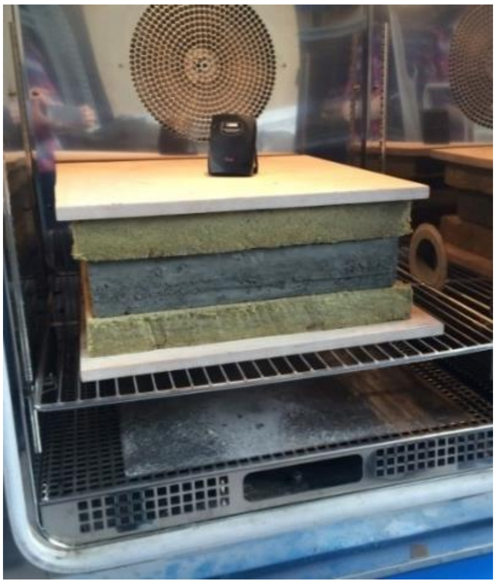

Figure 3. Chamber conditions for reinforced concrete structure

The sample was placed in a chamber (initial temperature inside the structure was approximately 21 °C) and released to an air temperature of 0°C degrees. The sample was at 0 °C degrees for 30 minutes. Then followed an increase of temperature in the chamber to 25 °C degrees. The sample was heated until the sensor inside the structure began to register an increase in temperature. Due to the fact that the material is thermally stable, it continues to cool down, even if the chamber has at plus temperature. Then the material was cooled until the temperature of the sensor began to fall.

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The second structure – brickwork.

Similar to the last one, it consists of the following: a wooden board, a heater, a brick sample. The time and temperatures were the same as the experiment of reinforced concrete structure. A sample is shown in Figure 4.

Figure 4. Chamber conditions for brick structure

Results and Discussion

The result of the experiment is shown in Figure 5.

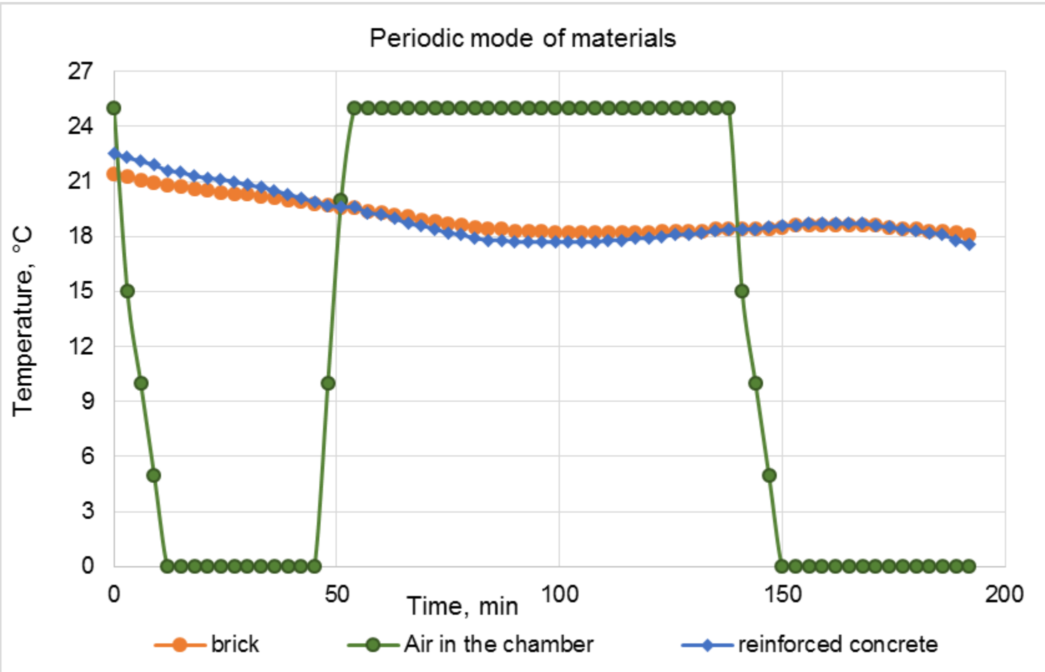

Figure 5. Internal air temperature of the structures

As a result, it is seen that when cooling for the same time, the air inside the brick structure cools down considerably less than in reinforced concrete structure. Furthermore, when heated, the reinforced concrete continues to cool down, the brick reacts more stable to temperature changes. At the second cooling phase the brick keeps an average temperature of 18.5°C. In contrast to the reinforced concrete which continues to give off heat, and then reduces heat.

This is due to the fact that reinforced concrete is considered to be an inhomogeneous material and the reinforcement works as a bridge of cold, which can be clearly seen on the resulting graph.

In consequence of this, it will be most comfortable to stay indoors, under the given conditions, with a reinforced concrete structure because it will be considerably hotter under cold temperatures and colder under high temperatures. But is the brick the one considered to be the most thermally stable material, so for purposes of this paper is recommended brick as the appropriate material due to the fact that keeps temperature in a more stable way than concrete does, is more suitable for keeping indoor conditions in a more unchanging manner.

Analyzing each phase of drastic temperature changes has been found the following. For the first drop down both materials release energy as is expected, the concrete has a considerably steeper slope than brick does in the graph. The second phase is when temperature increases drastically; both materials continue to release until they get a stable point and begin to absorb energy. Concrete shows a changes in its graph´s slope in a more differentiable way than brick does, its slope changes faster. The third phase is the final drop down of temperature; both materials keep increasing temperature until their stable point when they begin to drop down, ones more, is the concrete the one with more pronounced changes of slope in the graph.

Analyzing each phase of the experiment the results show that internal temperature of both structures has the form of a smoothly varying function.

It is shown the good convenience of bricks for guarantee a more suitable condition of comfort inside structures. In article [15] authors also considered behavior of materials and measured temperature of material in different points. This article consider indoor temperature of the air under the condition of different barrier materials.

A point to be taken into account is the humidity factor, the experiment was made with 55 % humidity but in tropical conditions it may reach up to 90%. Humidity does not affect the inside temperature but it affects the human body. For further research it is recommended to install humidity sensors and to consider the effect of heat and humidity regime in the room. As exposed in other articles [3, 9] is highly important the fact of keeping appropriate conditions for residents, both offices and living spaces. Results support the fact that more than considering price of materials should keep in mind also the advantages over long term periods [19–23].

Conclusion

This paper aims to compare the thermal behavior of the typical materials for constructions in tropical weathers, particularly was choose Colombia as a representative to the normal temperature characteristics for these types of regions. Bricks and reinforced concrete were the analyzed materials. The results showed a difference between both materials which can be considered decisive at the moment of taking a decision for choosing the most appropriate construction material. For drastic changes of temperature it has shown the way bricks and concrete behave; been more recommendable to have the first ones as an element of thermal stability material which is translated into more conformability for tropical climates.

According to results, the following conclusions have been done:

1. Full cooling time of the reinforced concrete was 90 minutes, cooling time of the brick was 99 minutes;
2. Then temperature in the chamber was 25 °C again. Materials kept cooling down for 36 minutes (reinforced concrete) and 45 minutes (brick).
3. Full heating time of the reinforced concrete was 66 minutes, brick was 54 minutes;
4. Then temperature in the chamber was changed to 0 °C. Materials kept heating up for 6 minutes (reinforced concrete) and 3 minutes (brick).
5. The lowest internal temperature was for reinforced concrete structure (17.6 °C).
6. Both materials are comparatively resistant to sudden temperature changes, but temperature range of the reinforced concrete (4.9 °C) is bigger, than brick (3.3 °C).

For drastic changes of temperature it has shown the way bricks and concrete behave, been more recommendable to have the first ones as an element of thermal stability material which is translated into more conformability for tropical climates.

As a further study may be conducted an assessment for drastic cooling and heating with a higher percentage of humidity. Moreover would be appropriate to consider the same methodology in 1:1 scale conditions, this is by installing all the equipment and sensors inside concrete and bricks buildings and collect supporting results.

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