# Improving the Thermal and Structural Characteristics of Concrete Hollow Blocks using Potato Agro Waste

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**ABSTRACT**

**The building envelope is a predominant component in the energy consumption of architectural space. The lower energy efficiency the envelope achieves, the higher energy consumption is required to maintain thermal comfort in architectural space. This paper aims to explore the effect of using potato agro-waste on the thermal and structural characteristics of concrete hollow blocks. Utilizing agro-waste in building blocks is not a novelty, yet, targeting highly engineered materials, like Cellulose Nano Platelets (CNP), leverages nano-scale reinforcement, thus achieving enhanced properties with less materials. Using quantitative experimental methods, CNP modified concrete specimens are compared to control specimens. At 0.20wt% and 0.40wt%, CNP shows significant improvement in thermal conductivity. The compressive, flexural, and tensile strength were also improved with the addition of 0.20wt% CNP, whereas 0.4wt% addition recorded strength values similar to those of the control mix. The initial and secondary rate of absorption was remarkably improved for the mix with 0.2wt% of CNP. The optimum amount of CNP to be added was, thus, 0.2wt%, the results of which were used to perform environmental simulation employing DesignBuilder and SimaPro. The percentage of dissatisfied people for Predicted Mean Vote (PMV) between -0.5 and 0.5 is less when deploying modified hollow blocks for the walls. The use of potato agro-waste modified concrete hollow blocks reduces the zone sensible heating and zone sensible cooling of a space, lowering the energy requirements for comfort optimization and, therefore, enhancing the building's energy efficiency.**

***Keywords-agro waste; concrete hollow blocks; environmental performance; thermal comfort***

## I. INTRODUCTION

Concrete hollow blocks are considered the most affordable building envelope, and thus the most commonly used and with the widest spread [1]. They are precast standardized rectangular blocks, having one or more voids to reduce their weight [2]. Since they form most of the building envelopes, they have a significate influence on the performance of the architectural space. If wall components are of low energy efficiency, space requires higher energy consumption to maintain thermal comfort [3]. Thermal comfort on the other hand has a critical role in maintaining users' well-being [4].

Performance is the ability of a space to achieve optimum efficiency while meeting the function requirements for the duration of the building's life [5]. It is, therefore, a quantifiable measure of how well a required function is achieved [6]. Environmental performance, specifically, can be defined as the measurable responses of systems with reference to environmental quality indicators [7]. It is the influence of a building on its environment in terms of resource consumption, waste generation, and emissions [8]. Targeting an energy efficient building envelope that maintains thermal comfort with the least load on heating and cooling systems, the search for enhanced properties of building materials has gained a big share of interest in the research field. One approach to achieve this is the integration of agro-waste with conventional materials.

This research aims to explore the effect of using potato agro-waste on the thermal and structural characteristics of concrete hollow blocks.

To accomplish this, the paper targets several objectives:

- Reviewing the literature.
- Recognizing the effect of adding agro waste on the mechanical and physical properties of concrete mixtures.
- Comparing via simulation the thermal performance of a space using control hollow blocks against those modified by adding CNP.

The search for waste integration with conventional building materials is not a new approach, especially in concrete; even very recent trials have tested the impact of integrating four different waste materials on concrete [9]. Yet, only a few tackle organic waste. The use of organic materials is relatively expensive and might compete with the food market, creating the need for green strategies in manufacturing [10] or cheap resources, such as the organic feedstock from agriculture and agro-industrial waste. This is not a novel approach though; the integration of straw with cementitious materials was validated to have a positive influence on both the structural and thermal properties of construction materials [11]. Agro-waste is a potential resource of nano-materials due to the huge amounts generated worldwide and their chemical composition [12, 13]. These materials could be nano-adsorbents, nano-silica, nano-cellulose, nano-carbons, and nano-cementitious additives [12]. Table I shows the latest research on the aforementioned materials.

TABLE I. MANAGEMENT OF SOME AGRO WASTE WITH REFERENCE RESEARCH

| Material | Agro-waste | Ref. |
|---|---|---|
| Thermal insulation | Straw | [12] |
| Adsorbents | Almond and walnut shells | [14] |
| | Leaves of Saccharum officinarum | [15] |
| | Wheatand barley grass wastes | [16] |
| Silica | Walnut and groundnut shells, banana and orange peels, coconut husk | [17] |
| | Rice husk ash | [18] |
| Cementitious additives | Rice husk ash | [19] |
| | Rice husk ash | [20] |
| | Palm oil fuel ash and rice husk ash | [21] |
| Cellulose | Pulp of pili tree (Canarium ovatum) | [22] |
| | Tea stalk | [23] |
| | Cotton residues | [24] |
| | Nypa Fruticans trunk, coconut husk fiber, and rice husk | [25] |

Two-dimensional nanoplatelets have been tested as a partial replacement for cement in concrete mixtures using sugar beet root pulp and carrot residue in 2019 and 2020, respectively [26, 27]. The addition of 0.2wt% of sugar beetroot nanoplatelets was concluded as optimum; 75% increase in flexural strength, 200% improved modulus of elasticity, 88% more fracture energy, and 106% increased fracture toughness [26]. The addition of carrot residue nanoplatelets into the concrete mixture suggested similar results, with less influence; 23.2% increase in compressive strength compared to 75% with sugar beetroot [27].

Indeed, throughout literature, the focus has been on the mechanical and physical properties of materials, and mainly of concrete elements and building envelopes. Yet only few target a specific use of the studied materials and most of them end up with recommendations and fail to scale up to commercial level. As in covering this gap, the novelty of the research lies in specifying the intended use and comparing the resulting properties with technical standards.

## II. METHODOLOGY

The research uses the quantitative approach to assess the impact of integrating potato nanocellulose with concrete. Then, experimental methodology was used to determine how that would affect the environmental performance of a space built with that material. Along the study, the research refers to experts in the industry of construction products, to follow along with the methodology and assess its practicality.

### A. Materials and Methods

First, potato peel was field collected from local business as agro-waste. The peel was then chemically treated in a local workshop with the use of sodium hydroxide (NaOH), hydrogen peroxide ($H_2O_2$) and then oxidized using ammonium persulfate. For mechanical treatment, the substance was ultrasonicated into nanocellulose and characterized in specialized laboratories at Beirut Arab university laboratories, Faculty of Science. For the concrete specimens, a control specimen was then prepared using Al Sabeh PA-L 42.5, Limestone Modified Portland Cement. In addition, two modified specimens were prepared with 2wt.% and 4wt.%. The specimens were prepared, cured and tested at the materials laboratory at the Faculty of Engineering, Department of Civil Engineering at Beirut Arab University.

Finally, the new material properties were used to simulate a residential unit using DesignBuilder. The unit was modelled using Revit. Also, a control simulation was done using conventional material. The workflow is represented in Figure 1.

### B. Selection Criteria of Potato Peel Agro-Waste

The contribution of potatoes to the world's global food production was assumed to exceed 6% in the coming decade, that is double its current rate [28]. Regionally, Lebanon was considered an important producer of potato, with two major harvesting areas: Akkar and Bekaa. Potato related industries such as potato chips, frozen French fries, starch, and many others were widely spread in these two areas, resulting in tremendous amounts of potato waste. The sample was collected from a small local business.

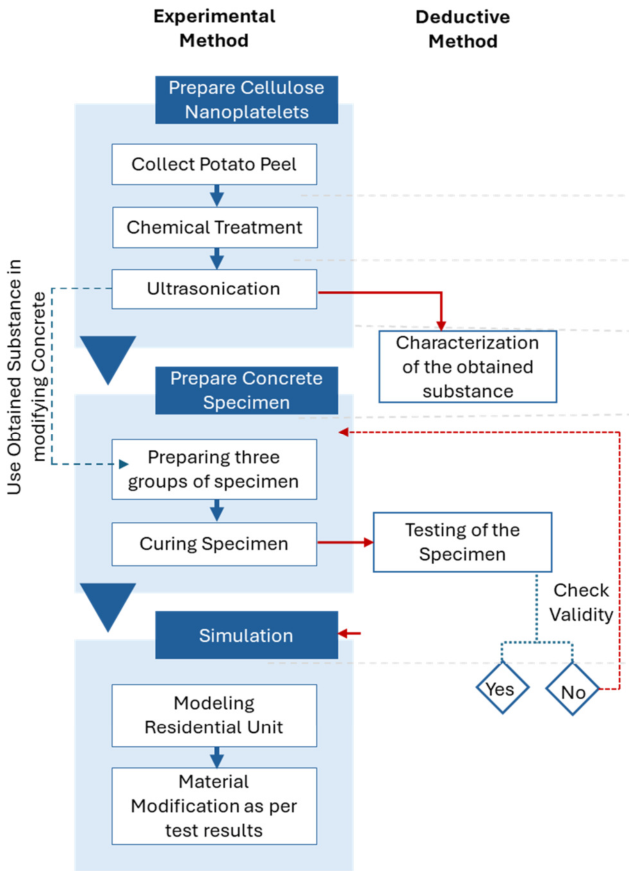


Fig. 1. Diagram explaining the methods of research.

## C. Preparation of Cellulose Nano Platelets

After collecting clean peel, the process of preparing nanocellulose began with the chemical treatment at a local workshop, as per the method verified in [29]. The steps followed from raw potato to pure cellulose are depicted in Figure 2. At the end of each stage, the yield was calculated:

$$yield = \frac{obtained\ weight\ after\ treatment}{original\ weight\ of\ treated\ substance} \times 100 \quad (1)$$

First, the collected potato peel was dried in the sun for 3 days. Once completely dry, it was grinded using domestic grinder, then pulverized using a metal mesh of size 40. It was then cooked with distilled water, collected from the Faculty of Chemistry at Beirut Arab University with a solid-to-liquid ratio of 1:10 for 10 min after the mixture reached a boiling point. The purpose was to eliminate the starch and keep the lignocellulose. To achieve this, the mixture was homogenized using a high-speed homogenizer for another 10 min. Then it was filtered and washed thoroughly several times until all starch was removed. A small amount was bleached and tested using iodine to verify the removal of starch. To extract the cellulose from the obtained material, Sodium Hydroxide was utilized to perform alkaline treatment twice, using NaOH 4% solution with a solid-to-liquid ratio of 1:20 under heat for 10 min. After each time, the substance was washed thoroughly on a fabric filter using distilled water. Later, the substance was bleached utilizing alkaline Hydrogen Peroxide with solid-to-liquid ratio of 1:20, where 1% of NaOH was combined with 7.5% $H_2O_2$. The treatment was carried out for 4 min. Again, the substance was washed using distilled water, dried, and weighted.

The pure dried cellulose was first soaked in distilled water with a solid-to-liquid ratio of 1:50 for 8 hours. Then it was disintegrated and the excess water was later removed using a funnel and a filter sheet. Clear water was added again with a ratio of 1:30 this time, and following this the containers were closed and heated in water bath to 70 °C. Ammonium Per Sulfate (APS) of 98% purity were added along with hydrogen chloride (HCl) of 37% concentration. The mixture was heated for four hours while stirring continuously. After that, the reaction was stopped by cooling the mixture in an ice bath until it reached 15°C, and it was, subsequently, filtered and washed thoroughly. In the microbiology labs of the Faculty of Science at Beirut Arab University, the substance was dissolved in distilled water with a ratio of 1:40, and was ultrasonicated for 30 min using ultrasonic homogenizer SONIC-650W until it was visually seen to have increased viscosity, as displayed in Figure 3.

## D. Recognizing the Mechanical Properties of the Concrete Specimen

Based on the Eurocode2 (EN 1992-1-1), the concrete used for exterior walls should have a compressive strength of 25-30 MPa [30]. Aiming for that, three groups of specimens were prepared: a control specimen and two modified specimens with 0.2wt% and 0.4wt%. The used cement conforms to ASTM C595 as Portland Limestone cement Type I L [31]. Coarse aggregate with an average size of 12.7 mm and of 9.5 mm was selected. Almost equal quantities of natural and crushed sand were utilized, while distilled water was also used.


Fig. 2. Process from potato to bleached pure cellulose.

Fig. 3. Ultrasonication of the substance to achieve nano fibrillated cellulose as a viscous matter.


Fig. 4. Specimen preparation: (a) weighing the constituents, (b) preparing the molds, (c), (d) pouring the concrete.

The used molds conform to ASTM C31 standards [32] in terms of material, shape, and size. First, they were oiled and concrete was poured in three portions, tamped, and vibrated. On the second day, specimens were unmolded and cured at the lab at a temperature between 16° C and 27° C as per the standards. Figure 4 represents some steps of the specimen preparation process.

*E. Measuring the Thermal Performance of Concrete Hollow Block via Simulation*

The in-hand case study is a typical residential unit in Bekaa, Lebanon. The form of residential units in the selected area is mainly single-family houses, of 1-3 floors, or residential apartments of 1-4 apartments per floor. The units are typically made up of a living room, kitchen, and 2-3 bedrooms with the corresponding services. The module of construction usually ranges between 3.5-4.5 m. Most rooms are of 4x4 m dimensions.

The simulation considers a typical room within a residential unit, of 4x4 m dimensions, and 3 m height, on the ground floor, with no upper floors, to minimize additional factors. The room has two exterior walls and two interior walls as per the indicated key plan, with an interior door linking the room to the rest of the house, and a window to the exterior. The model is represented in Figure 5.

The climatic profile of Bekaa was created on DesignBuilder, to ensure that the simulation considers the specific climate of the region of the case study. To perform the simulation, the space was modelled using Revit. Then, the energy model was imported to DesignBuilder version 4.5.0.148, where the simulation was performed with the aid of EneryPlus version 8.3.0.0001. The simulation was carried out for over one year, based on the project data represented in Table II.

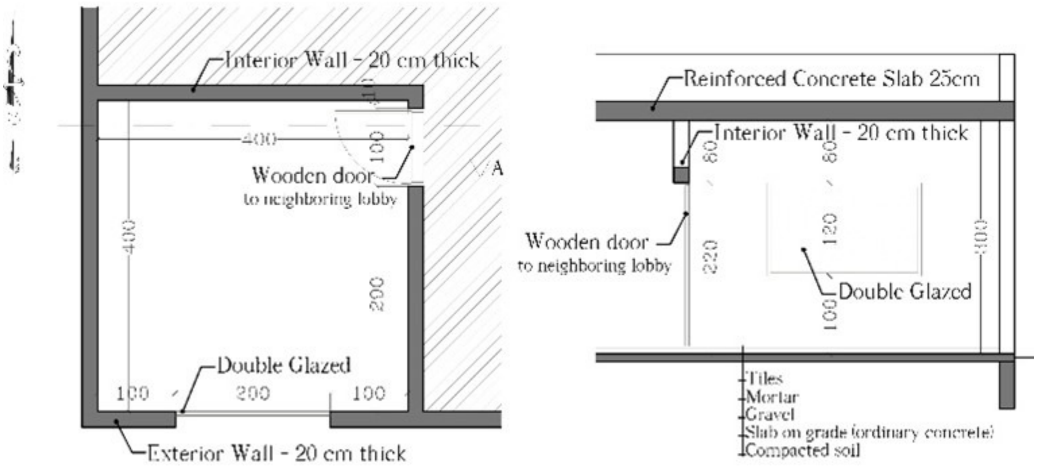


Fig. 5. Schematic plan and section of the modeled room used for simulation (illustration by author).

TABLE II. PROJECT DATA IN DESIGNBUILDER

| **Project data** | |
|---|---|
| Report generation time | 21/01/2025 |
| Sky model | CIE overcast day (specify illuminance) |
| Location | Houche-Al-Oumara |
| Working plane height (m) | 0.750 |
| Max grid size (m) | 0.200 |
| Min grid size (m) | 0.050 |
| Daylight factor threshold (%) | 2.000 |
| Illuminance lower threshold | 250.000 |

## III. RESULTS

Over a period of sixty days, the necessary tests were conducted and the following results were recorded:

*A. Slump:*

The slump of the control mix, denoted as mix 1, was 225 mm, whereas that for mix 2, with 0.2wt% of CNP, was 198 mm, and for mix 3, with 0.4wt% of CNP, was 185 mm. All three mixtures are considered consistent based on ASTM C143/12 standards [33]. The same amount of admixture was used in all three mixtures (180 g), and thus it can be said that there is a slight decrease in workability. The form of the subsided concrete is a shear slump for all three mixtures, as shown in Figure 6.

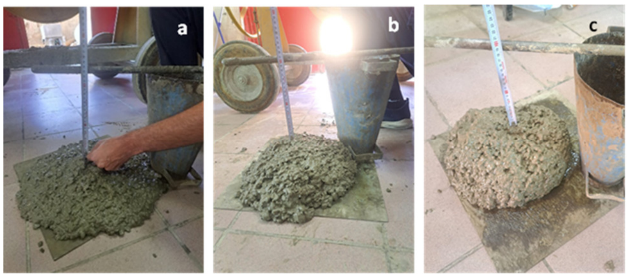


Fig. 6. Results of slump test: (a) mix 1 - control, (b) mix 2, (c) mix 3.

### B. Compressive Strength

The three mixtures at all testing ages have acceptable compressive strength, as per the American standards [34] and the European Standards [30]. On day 7, the control mix had the highest compressive strength. On day 14 the compressive strength of all three mixtures was similar. On days 28 and 42, mix 2 showed a more noticeable increase than both control mix and mix 3. The drop in the compressive strength of mix 3 at day 42 could be due to uneven mixing or curing, as the test was conducted on one sample per curing age.

### C. Sorptivity

At equal time intervals, and over three days, the mass of surface dried cubes submerged in water. The reported absorption rate shows that the control has the highest rate at the first min and on day 3 with I = 1.01 mm at 5 min, in comparison with the 0.39 mm for mix 2 and 0.845 mm for mix 3, and with I= 8.454 mm at the end of day 3 in comparison with 4.68 mm for mix 2 and 8.35 mm for mix 3. By spotting the recorded results of change of mass as a function of square root of time in seconds, as depicted in Figure 7, the trendline slope is calculated for the initial rate of absorption. For the control mix, the latter is 0.0245, whereas for mixtures 2 and 3 it is 0.014 and 0.0306, respectively, as portrayed in Figure 7.

In the same sense, the rate of absorption over three days was plotted and represented in Figure 8. The trendline between the end of day 1 and end of day 3 was used to report the secondary rates of absorption of the mixtures. The highest was for the control mix, with a secondary rate of absorption of 0.0183, followed by mix 3 with 0.0162. Mix 2 showed the best performance of all, with a secondary rate of absorption of 0.0076. At the end of day 3, the cube of the control mix increased by 85.45 g, mix 2 by 46.8 g, and mix 3 by 83.5 g.

### D. Thermal Conductivity

The thermal conductivity is measured using guarded hot plate apparatus. Readings from the thermocouples located 0.045 m apart are recorded for each of the specimens when a steady state is reached. The thermal conductivity is then calculated. The control specimen recorded 1.38 W/mK, which is similar to the normal range, validating the tests undertaken. Mixes 2 and 3 recorded a thermal conductivity of 1.2 and 1.06 W/mK, respectively. This indicates an increase of 13.01% and 22.84% for mixes 2 and 3, respectively.

### E. Environmental Simulation

The significance of the analysis of heating and cooling design results lies in identifying the size of the systems used, and the critical elements of heat loss and gains, while giving hints on energy optimization potential. This is supposed to ensure occupants' comfort with most efficient energy use.

The temperature results in the heating design indicate that when using modified hollow blocks, the radiant and operative temperature are slightly higher than with the control hollow blocks. Moreover, the heat loss in walls has decreased from -1.41 kW in the control to -1.09 kW in the modified blocks. The zone sensible heating, thus, decreased from 2.43 kW in the case of control blocks to 2.09 kW in the case of modified blocks.

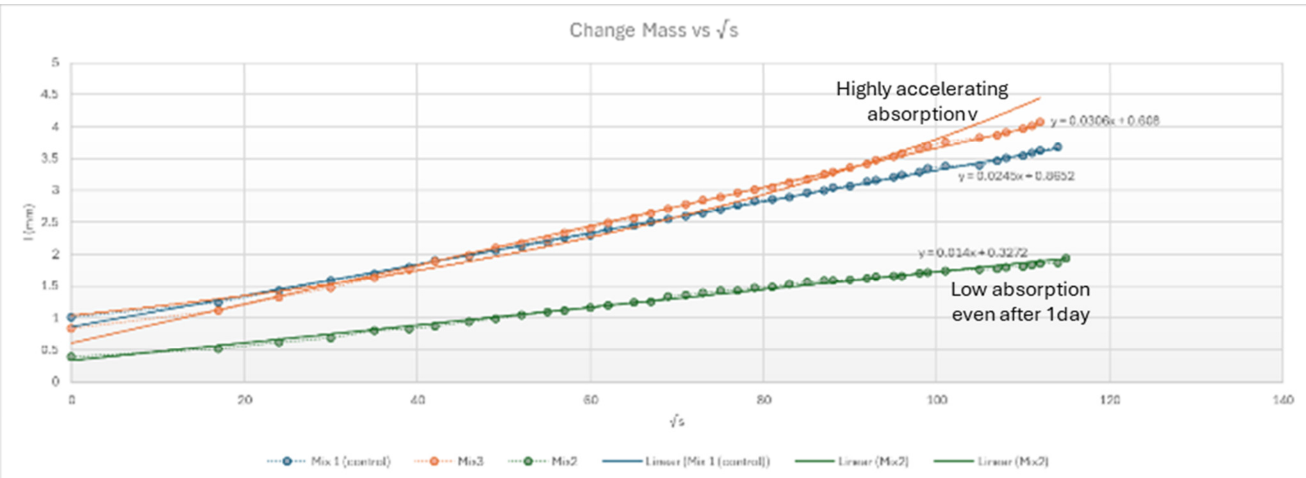


Fig. 7. Spotting rate of absorption as a function of square root of time between 0 and 6 hours.

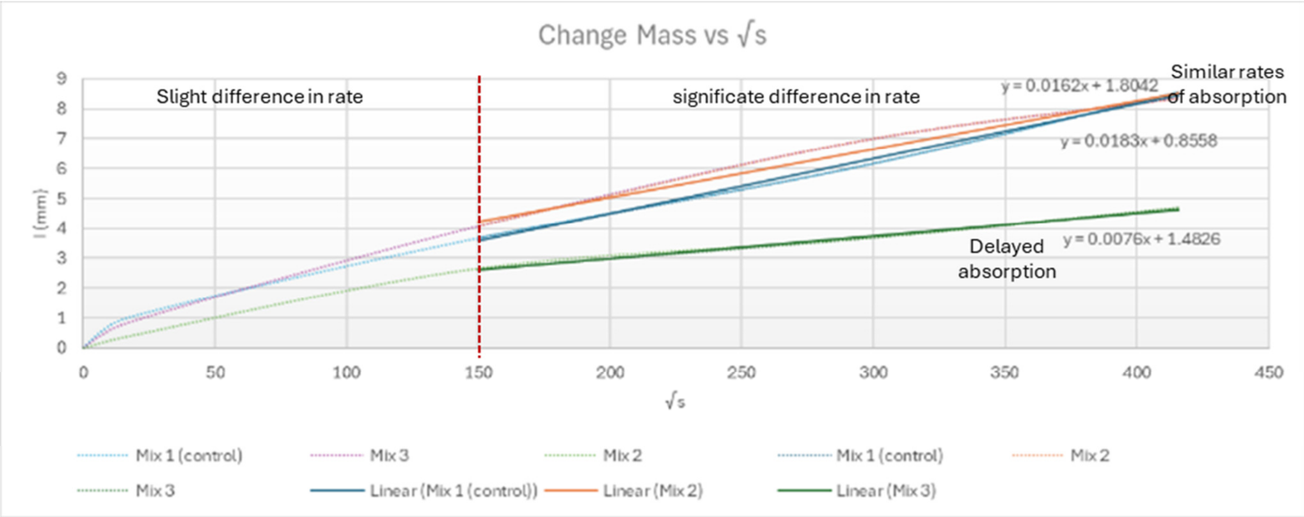


Fig. 8. Spotting rate of absorption as a function of square root of time between 0 and 3 days.

For the cooling design, the temperature and heat gains are recorded over one summer day. The air, radiant, and operative temperatures recorded a peak of 50°C in the control between 15:30 and 17:00, and 47°C between 16:00 and 17:00. The lowest temperature recorded was at 5:00 for the control with 25°C, whereas for the modified it was 26°C at the same time.

Marking the zone of PMV between -0.5 and 0.5, as evidenced in Figure 9, the Predicted Percentage of Dissatisfied (PPD) for the control mix is 10%, 5%, and 6.5% for PMV -0.5, 0, and 0.5, respectively. When using modified blocks for the walls, the PPD values decrease to 8%, 2.5%, and 4.5% for PMV -0.5, 0, and 0.5, respectively. The decrease in PPD indicates greater thermal comfort, therefore lower energy consumption for thermal comfort optimization.

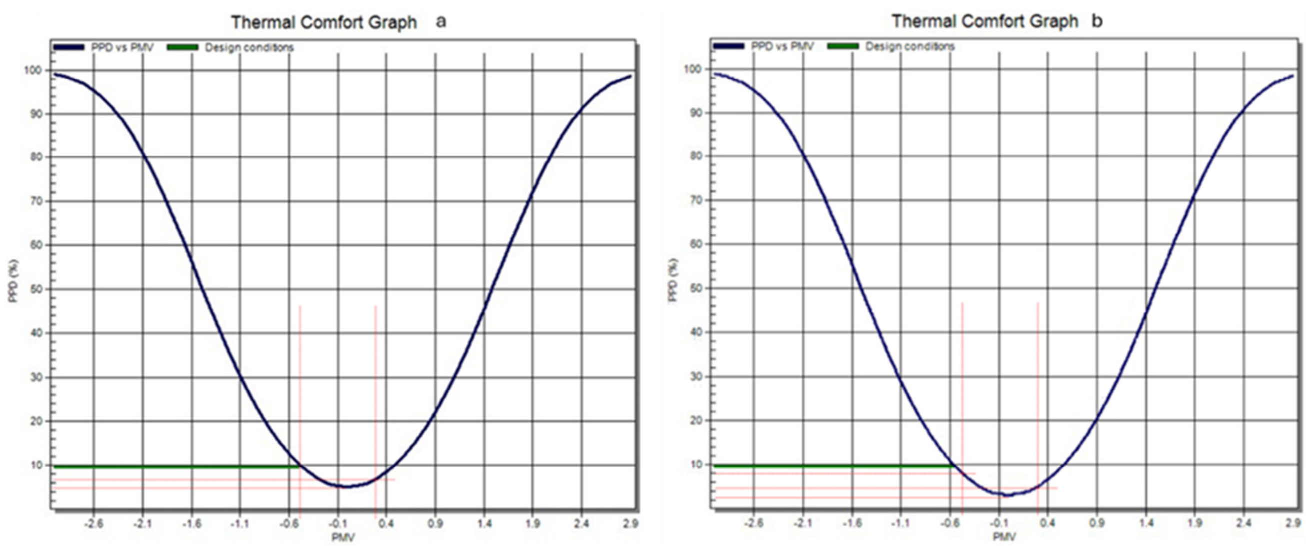


Fig. 9. Thermal comfort graphs: (a) control, (b) modified.

Considering the heat balance, all parameters seem to be similar except for the walls. The peak heat gain for the walls recorded less than 1 kW in the modified mix, whereas the peak heat gain for the control mix recorded more than 1 kW. The valley recorded -1 kW for the control mix, which was remarkably less for the modified mix, with a value of -0.65 kW. Similarly, the relative humidity in the control mixture fluctuated between 8 and 33%, whereas that in the modified one recorded a slightly less relative humidity of 31%. The delta between the peak and valley is less modified where the least recorded relative humidity was 11%. The relative humidity against the dry air bulb temperature hourly recorded during the time period of one day were plotted over a bioclimatic comfort graph, as per Olgyay's comfort criteria [35], as illustrated in Figure 9. It is noted that the corresponding scatter of the modified hollow blocks lie more in the practical and desirable comfort zone.

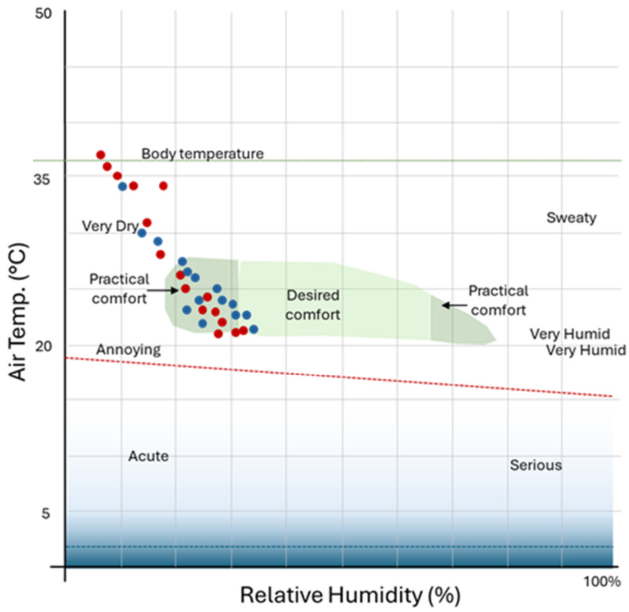


Fig. 10. Relative humidity vs air temperature of one day upon using the control concrete hollow blocks (in red) and the modified ones (in blue), plotted vs Olgyay's comfort criteria.

## IV. DISCUSSION

The process of extracting CNP was performed as described in [29]. To validate the former, its yield was compared to the one presented in the present paper. The yield of CNP production is 6.6%, whereas that in [29] was 6.7%, confirming that the process was executed successfully.

The use of 0.2wt% of CNP resulted in an increased compressive strength by 6.7%. As for the physical properties, the initial and secondary rates of absorption show improvement, with 42.85% and 58.47%, respectively. Similarly, thermal conductivity improved by 13.01%. The results are promising for the use of the material as precast building envelope elements. It is likely to have improved insulation, reduced energy demand to maintain indoor air temperature, as well as reduced thermal stress.

On the other hand, the use of 0.4wt% of CNP was found to cause a slight reduction in the compressive strength, without affecting the design goal; it still falls within the acceptable range as per the standards. The sorptivity of the mixture is similar to that of the control mix. The remarkable improvement is in thermal conductivity, with 22.85% improvement from the control specimen.

## V. CONCLUSION

Utilizing agro-waste in building blocks can achieve nano-scale reinforcement, enhancing the concrete's properties. More specifically, the addition of Cellulose Nano Platelets (CNP) in concrete blocks was found to:

- Slow down the crystallization and chemical reaction, and thus produce less dense dried mixtures at early curing ages, which later increase to normal levels.
- Enhance the calcium silicate hydrate (C-S-H) and the internal microstructure of the cured specimen.

On the other hand, the tests on potato peel CNP showed:

- A reduced workability, yet within the acceptable range.
- A remarkable increase in the thermal conductivity and rate of absorption.

Because of the improved thermal conductivity of the new concrete mixture, the heat loss and gain of the walls decreased by 22.7%, influencing the thermal behavior of space and reducing the sensible heating and sensible cooling zones. This could lead to lower energy requirements for the optimization of comfort in the desired space and potentially achieving greater energy efficiency than conventional materials without CNP.

Theoretically, the produced amount of potato peel in comparison with the yield of production and the optimal amount used can be considered a potential in the generation of hollow blocks. This procedure is more suitable for prefabricated elements, rather than cast on site. Yet, the upscaling to the industrial level can face many obstacles. The unskilled and untrained personnel, the lack of production lines, and the lack of interest are some possible limitations. The cost should be further investigated for further validation.

Finally, it is worth mentioning that the need for multidisciplinary research facilities was one major challenge for the study, in that there were several obstacles:

- Lack of understanding in laboratories outside the faculty of architecture on the link between plant extract and architectural application.
- Impossibility of processing the whole required amount at once, which caused delays in the schedule.
- Difficulties in purchasing the required chemicals and products individually.
- Inconvenient tools and machinery in the workshop where the extraction was performed.

The findings of the study are promising in several ways, mainly in terms of the physical properties of the obtained material. Yet, further research can include:

- The effect of using agro-waste on fire resistance, acoustic behavior, and durability of the materials.
- The possibility of decreasing the amount of cement in 0.2wt% CNP modified concrete.
- The effect of using potato peel CNP on the carbon footprint and emissions of concrete blocks.
- The influence of integrating agro-waste on the life cycle of building materials.
- The cost effectiveness and feasibility of integrating agro-waste into building materials.
- Generating a framework for utilizing agro-waste on a commercial scale.

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