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Informal settlements sustainable development: Comfort level enhancements through the Micro-Scale Intervention, Metamorphic Shutters, and its effect on the built environment of Cairo

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Abstract

The sustainable development of the built environment through informal settlements may introduce itself through micro-scale architectural interventions. This research's aim is to inspect whether the Metamorphic Shutters intervention can have a positive effect on the built environment through improving thermal comfort levels. The consideration of the residents' socio-economic dimensions was foundational to try and improve their overall quality of life using this simple intervention. The Literature suggests that the key problem with these interventions which have been designed before is the lack of economic and practical efficiency for informal settlement users due to them using expensive and inaccessible materials whilst using complicated construction methods. This makes it difficult for the interventions to be realized and repeated in informal settlements. Moreover, they concentrate solely on the lighting level enhancements rather than the effect of that on thermal comfort levels.

The Metamorphic shutters (MS) are rotatable horizontal louvers installed in window draft casements. The intervention's 2 main objective was to quantitatively test the possible thermal comfort and lighting level outcomes of the MS by controlling the amount of direct light which enters the room. The second objective was to qualitatively understand the end user's subjective perception of the intervention's practicality, lighting and thermal comfort outcomes. Finally, the final objective was to test the MS after particular modifications were made based on the end users' request to increase the amount of daylight entering the rooms. Both an experimental and mixed method approach-with both quantitative and subtle and subsidiary qualitative data-were used to carry out the research. The qualitative data was gathered by interviewing a sample of informal residents before and after the intervention's construction and installation whilst the Quantitative data was gathered by monitoring the Metamorphic Shutters' performance.

It is important to mention that the conclusions found that the Metamorphic Shutters had high and mediocre levels of thermal comfort level improvements which varied for both summer and winter due to the amount of direct sun light which the experiment room received. These are not solely a result of the residents' control over the shutters but also-to a large extent-an effect of the building orientation and of the neighboring buildings' heights which obscure sunlight during certain time periods of the day and during different periods of the year.

Keywords

Sustainable Development; Settlments; Metamorphic Shutters; Built Environment;

1. Literature review

Many interventions have surfaced throughout the past few years to help solve the problem of daylight and sunlight within poor lit spaces using different methodologies and materials. Vlachokostas and Madamopoulos (2015) developed a liquid filled prismatic louver (LFPL), which is an equilateral cross section prismatic configuration filled with water. Its particular shape was chosen because of its construction's simplicity and the equilateral triangle's potential to redirect light through refraction or reflection. Its triangular cross section had side lengths of 7.62 cm and a cross section thickness of 0.32 cm. It also performed both daylight and thermal energy harvesting. It allowed for better uniformity and higher illuminance levels whilst actively managed infrared radiation heat within the water volume and used it to assist in secondary thermal energy applications such as room heating. The lighting levels it provided lived up to the ISO/TC 274 (2005) indoor lighting standards for office buildings.

The complication this intervention presented is that it did not handle overheating or take the topic into consideration from inception as the refracted sun light rays are a sure method to increase heat gain within a space. As demonstrated in Figure 1, the bottom panel provides viewing from the inside to the outside thus takes into consideration the occupants self-comfort but this still does not explain how the occupants feel about their vulnerability to outside gazes. In terms of practicality its manufacturing and use would be costly due to its acrylic boards, motor installation and detailed assembly. It would also prove as less practical due to maintenance given that it will be used in informal settlements where appliance maintenance is an extreme financial burden.

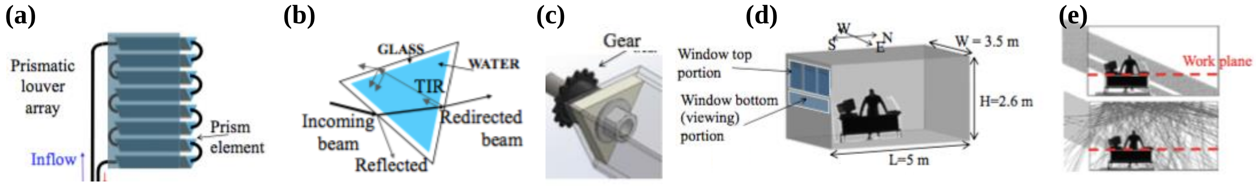


Figure 1.a. The figure shoes the inflow and movement of water from one prism to the other. Figure 1.b. The cross section demonstrates how the natural light beams are redirected through the LFPL. Figure 1.c. A rendering of the mechanism rotating the LFPL. Figure 1.d. Dimensions of the room and LFPL intervention. Figure 1.e. Cross sections of the room demonstrating the resulting outcome of the LFPL installation (Vlachokostas and Madamopoulos, 2015).

The recent development of high rise buildings in informal settlements has deprived the buildings with lower heights and alleys from sunlight causing health problems. To tackle this predicament, a sine wave-based panel was designed by El-Henawy et al. (2014) to redirect or diverge light downward to enhance the level of illumination by 200% and 400% in autumn and winter respectively. Both Experimental and simulation results conformed these results. The designed structure was manufactured using the compression molding technique on a flat PMMA sheet of 6 mm thickness. A hydraulic thermal press was used for both upper and lower platens (See figure 2).

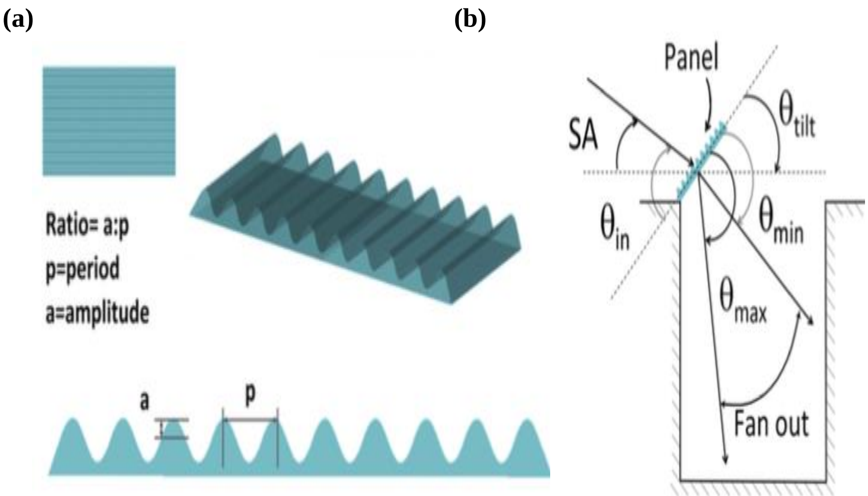


Figure 2.a. The rendering shows the form and dimension ratios of the intervention. Figure 2.b. The cross section of the street demonstrated the effect of the panel on natural street lighting.

The problems of the mentioned methodology is that it needs the use of acrylic which is expensive and rare to find within the Egyptian market. Also, common press machines are not available to all informal inhabitants nor can each inhabitant ensure that the design will turn out with the requested angles in absence of a professional engineer. Furthermore, the panels need to be installed across wide spans of roof top parapets to ensure that the light will be refracted enough to have the prospected effect on the alleyway. Since this would require a community-based initiative, its level of success would be dependent on their willingness to cooperate and share costs which would make this intervention highly unlikely to succeed without proper marketing and engagement.

A paper by Wagdy, Hegazy and Abdelghany (2015) was conducted to improve the possibilities of lighting conditions in informal settlement apartments. This paper aimed to identify the most reasonable retrofit window dimensions modifications in relatively narrow street widths (4, 6 and 8 meters wide) based on the amount of light reaching the ground floor level in order to receive more light (See Figure 3).The plugin Diva-for-Rhino, Rhinoceros 3D modelling software and Grasshopper were used to generate a parametric urban model based on a generic case study taken in Cairo, Egypt which would present Radiance and daylighting. The simulation took into consideration 3 factors which were window sizes and positions, street widths (ranging from 4 to 8 meters) and building heights ranging from zero to 9 floors. The results were that solutions included either changing window sizes or demolishing a couple of floors at the top of the building as suitable retrofits for increasing the natural lighting levels.

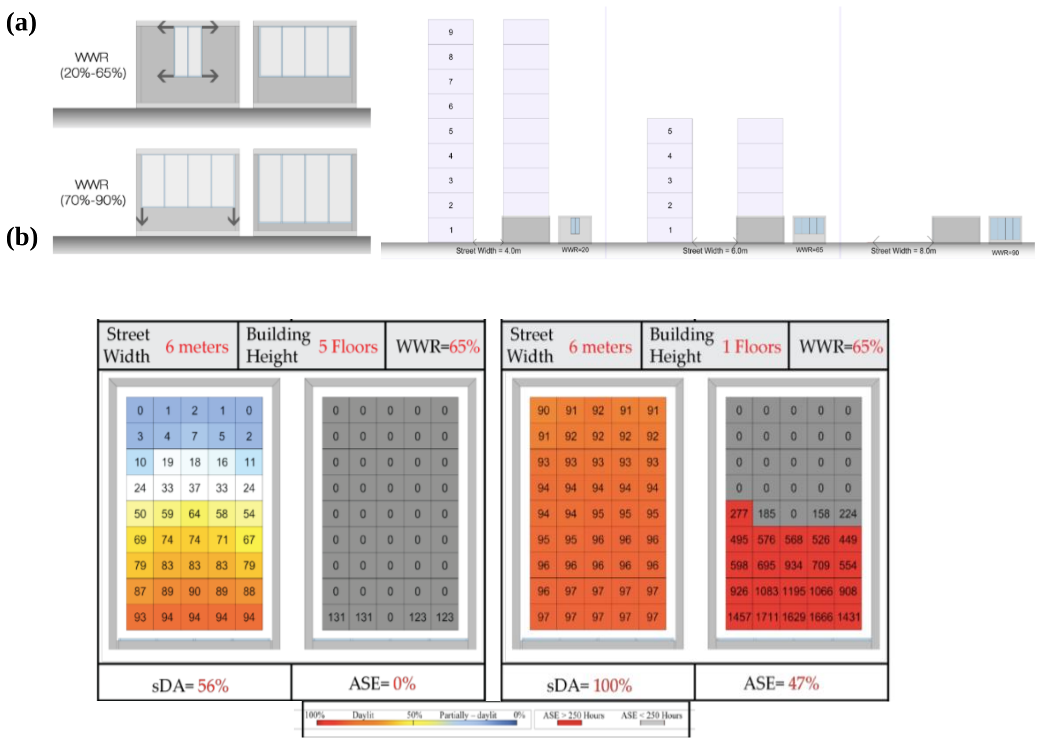


Figure 3.a. The different variables which are changed to provide different lighting results. Figure 3.b. The resulting lighting results for different factor settings. The South façade was examined, and a comparison was illustrated showing the difference between the daylight performance of one window ratio on the same street width but with different heights of opposite buildings. The tests revealed that the amount of sunlight exposure increases when decreasing the number opposite storeys and also the same happens with larger street widths.

Although the previous study provides a simple and feasible intervention, it does not address the fact that the larger window ratios would decrease the levels of privacy within the household requiring more curtain devices. Also, increasing the window ratios would definitely increase the amount of heat gain within apartments which would cause thermal comfort dissatisfaction. The suggestion to remove floors for buildings which obscure the sun's light is extremely controversial as owners are very keen on keeping each floor as an investment and asset that cannot go to waste for any reason whatsoever.

2. Methodology

Since the case study objective needed both quantitative and qualitative data to be fulfilled, a mixed method approach of both action and quantitative data collection research approaches were used in order to provide positivist and interpretive approaches. The use of the positivist approach presented results as fixed truths and objective facts whilst the interpretive approach studied the sample respondents' subjective views through semistructured interviews (Crotty, 1998, cited in Gray, 2004). Both descriptive and analytical surveys were used to provide a more positivist approach using the descriptive survey and an interpretive approach using the analytical survey. This allowed for both Nomothetic and Idiographic findings to be obtained. By selecting the case study approach, it was possible to focus on a single sample which provided abundant amounts of information both before and after the MS' design, construction and installation to ensure an effective design of the shutters and accurate onsite measurement readings after their realization.

After which 2 apartments were selected to act as control and experiment rooms for measuring the outcome temperature and lighting readings. Both apartments were located in the same building and on the same floor. The rooms were opposite to each other (See figure 4.a). The sample respondents chosen were in the flat towards the South which is highlighted in yellow within the figure. The respondents living in the flat were a purposively non-random sample in which the sample's economic, social and residential status was known in order to be an almost even and appropriate representation of the greater target population-informal settlement residents in Southwest Cairo-whilst providing in depth and detailed data and responses on the fieldwork carried out.

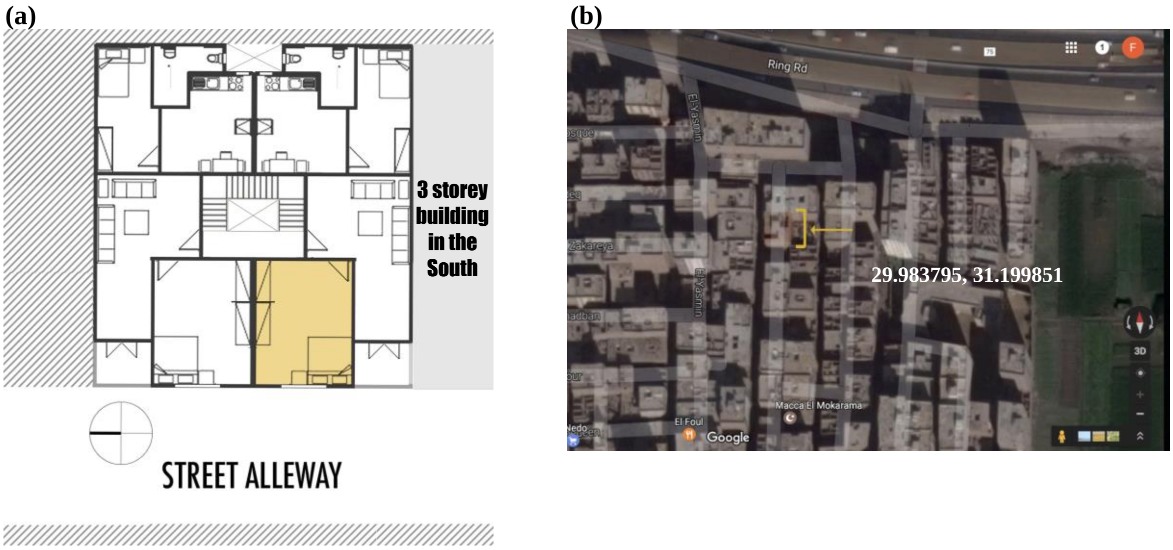


Figure 4 (a) The figure is a plan describing the experiment and control flats that were used (Author, 2017).

Figure 4 (b) An image from Google maps of the building location (Google maps, 2017).

The sample was a nuclear family with a 45 year old painter (Respondent B) and his-once nurse-25 year old housewife (respondent A) with 3 children ages 4,3 and 2. The bedroom in the neighboring apartment was used as a control sample. The tenant of the neighboring apartment was the sister of the painter, which allowed further cooperation on allowing the author to take readings during the mentioned 2 main seasons of the year at which the readings were taken for comparison. This also allowed for Respondent A to visit the flat regularly and experience first hand the lighting and temperature differences between the control room and the experiment room allowing her to make comparisons. The person that was interviewed extensively was Respondent A as she was the one using the MS daily whilst Respondent B (Respondent A's husband) was out during that time at work. The local carpenter (Respondent C), aged 50 of whom which owns his own modest workshop 2 streets away from the building's location, was selected to build the MS. He was interviewed before and after the construction process to provide information on how practical the intervention's realization is.

The control room had conventional shutters which prevented the light from entering in, although they were left open during most of the reading measurements. The reason for this will be explained in the next paragraph. The experiment room had the MS installed with the appropriate angle needed for the desired effect for each season.

The mentioned respondent sample said in a semi structured interview conducted before the MS construction that the current conventional window shutters are left open all year long to allow for ventilation throughout the hot months and to allow light throughout the winter months and that she only closes them in the evening or when needed for privacy except during the summer in which the shutters are closed at noon to prevent the sun's direct light from entering the bedroom causing the room temperature to raise up to even higher temperatures. This was taken into consideration during the monitoring process by leaving the shutters in the control room closed for half an hour before taking the light and temperature readings for both rooms but then they were left completely open form 12:30 pm to 4:00pm.

The MS post construction phase required readings to be taken during certain intervals of the year. The readings were taken onsite in the sample respondent's home for a week during the 2 main climatic periods of the year, the 20th of January (coldest week of the year) and the 6th of June (hottest week of the year). The outdoor ambient temperature readings of the street were taken 1 m outside of either bedroom's window. This was possible my means of attaching the digital thermometer to an extension rod. In each room, the temperature and light intensity measurements were measured at 1 m and 3 m away from the window towards the inside of the room and then an average was calculated for both readings. The author made sure that the direct light rays did not touch the light meter in order for the results to strictly present the daylight results.

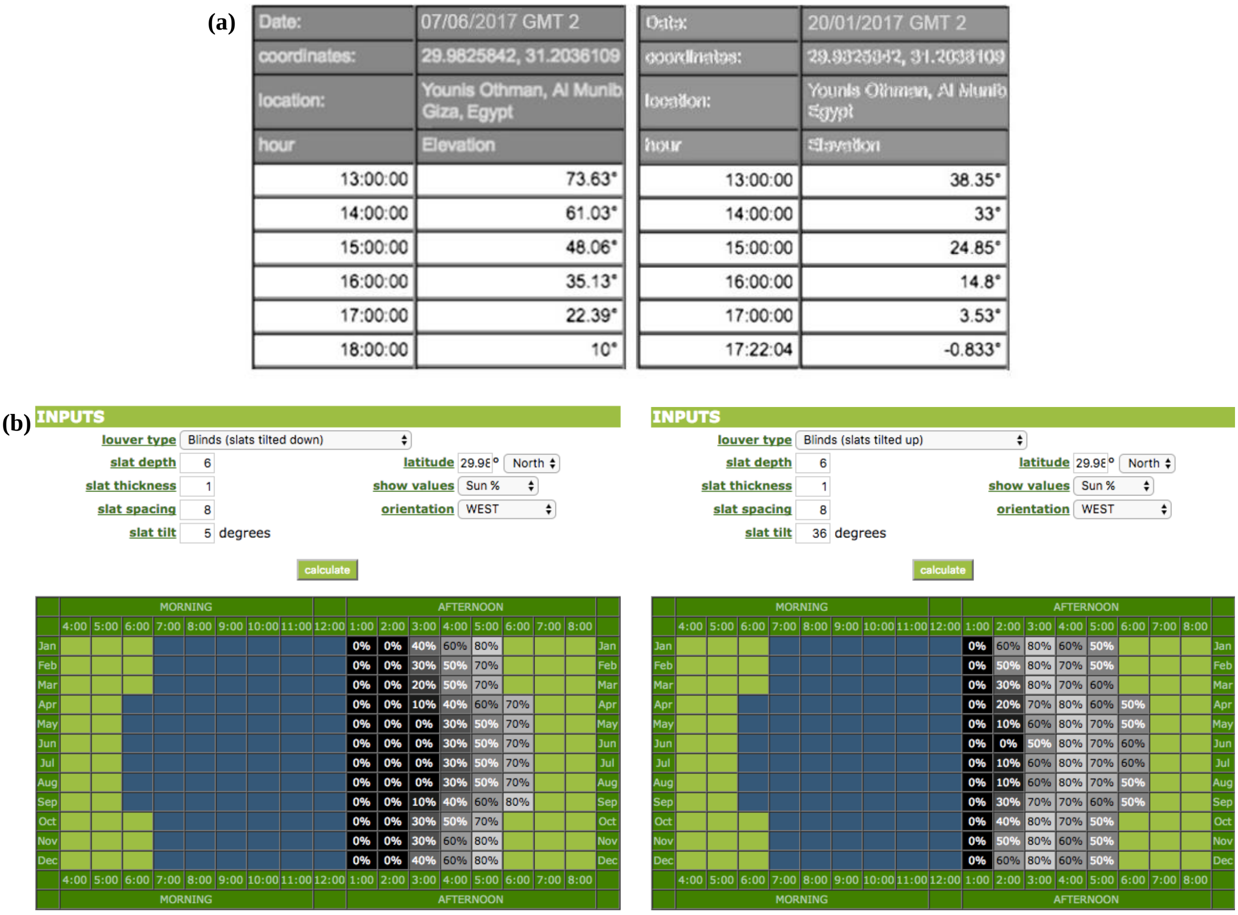
3. Results

3.1. Quantitative results at the MS pre construction stage

The table values present the sun's angles of incidence from 1pm to 4 pm during the presumed hottest and coldest times of the year (See Figure 5.a). These angles were used to then determine the angle that will be used to allow the maximum amount of direct sunlight in winter by calculating the average angle for each month. The second angle calculated was one that ensured no direct sunlight would enter the experiment room in the summer time during the time frame used, also an average for each moth was calculated. This was done so that the users could rotate the louvres to the optimum angles during the time periods where the author was not present so as to provide qualitative feedback that was as valid as possible of their experience with the MS. A decision was made that the glass panels in both rooms were to be closed from 12:30 pm to 4:15 pm ensuring the prevention of heat loss or gain through ventilation so as not to effect the resulting differences in temperature due to lighting levels. This was secondary to the precaution taken of leaving the shutter drafts wide open from 12:30pm to 4:15pm in the control room.

An online shading and lighting calculation site was then used in a trial and error process after the calculation of both average elevation angles were calculated. The site was used to test the subtle differences in the percentage of direct light penetration after using the appropriate angle for each season. The louver summer angle was set to 5 degrees inwards towards the experiment room on a horizontal axis to ensure the prevention of any direct sunlight from entering but also allowing for indirect light to enter in June. The louver winter angle was set at 32 degrees inwardly and on a horizontal axis as well as that was the angle that was guaranteed to let the most amount of direct light in from 1 pm to 4pm in January. The location's latitude and orientation were inserted into the online simulator (See figure 5.b).

It is important to mention that the apartment which had the experiment room had its south facing wall exposed to direct sun exposure all day long since the adjacent building to the South wall was only 3 storeys high thus leaving the outer side of the apartments living room wall exposed to the sun. At the start of the experiment, both the experiment and control rooms were examined with both windows casements closed and the shutters wide open to reveal if there were any temperature differences between them before installing the MS. The readings showed that the experiment room was always 0.3°C to 0.5°C warmer than the controlled room, this could have attributed to the apartment's south wall exposure to the sun thus gaining more heat. This difference in temperature was taken into consideration when the temperature results were presented in tables by reducing each value in the experiment room by a value of 0.4°C (the average of 0.3 and 0.5 degrees) in order for the comparisons between the rooms to be as valid as possible.



(a)

Date:	07/06/2017 GMT 2
coordinates:	29.9825842, 31.2036109
location:	Younis Othman, Al Munib Giza, Egypt
hour	Elevation
13:00:00	73.63°
14:00:00	61.03°
15:00:00	48.06°
16:00:00	35.13°
17:00:00	22.39°
18:00:00	10°

Date:	20/01/2017 GMT 2
coordinates:	29.9825842, 31.2036109
location:	Younis Othman, Al Munib Egypt
hour	Elevation
13:00:00	38.35°
14:00:00	33°
15:00:00	24.85°
16:00:00	14.8°
17:00:00	3.53°
17:22:04	-0.833°

Figure 5 (a) Snapshots of the elevation angles for the sun's rays during the hottest and coldest times of the year which were used to calculate the average needed angle for preventing and allowing the maximum amount of direct light from 1 pm to 4 pm in the winter and summer receptively using the MS (sunearthtools.com, 2019).

Figure 5 (b) Snapshots show the outcomes of the used MS louvers' tilt angles for both maximum or minimum direct light outcomes (sundesign.com, 2016).

3.2. Qualitative Results at the MS pre construction stage

Before the construction of the MS, a 1:20 model of the MS was made and shown to the selected sample respondents. The model was an exact replica of the image rendering in Figure 6. It was made clear to the respondent that this was only a prototype. The model was made realistic by means of laying the foam louvers in a foam board and by providing a 1:20 human figure which attracted the attention of the sample respondent and made the MS much clearer and understandable.

Respondents A and B made it clear-after a long discussion-that they wanted the MS to be installed in the form of 3 window drafts dividing the whole elevation and not 3 openable and 3 fixed drafts. Respondent A made clear that she would prefer the drafts to open horizontally and not vertically requiring much less physical energy and also providing much more entry of light when needed. The vertical rotation at the top of the window casement and at the middle did not appeal to her (See Figure 6). She saw them as requiring too much effort to change every time sunlight was needed and also she saw it as too much of an amendment to the classic window casement therefore keeping the drafts as convenient as possible was needed for her to volitionally use the MS louvers which she was not sure of whether she would like the outcome of or not but was open to the idea due to its hypothesized benefits. These changes surfaced and a rendering of the aspired model was made (See Figure 7.c).

Respondent C (the onsite carpenter) collaborated in the design phase by providing advice on the required louver section thicknesses and groove options to enhance the initial computer modelled design of the MS. The design of the window was originally made so that if the shutters were kept at a horizontal level, the glass panels of the window casements would not collide with them when the casements were closed. This was very obvious to Respondent C when he was shown the 3d design of the window on a laptop and was allowed to explore it. The proposed dimensions by the author was a window frame that was originally 8 cm in width and 4 cm in depth, and the casements' frame width was also 8 cm width and 4 cm depth. It was made clear that this was only a prototype design and that the metamorphic shutter window as a whole needed to cost less in materials than the conventional shutters window casement. Following this clarification, Respondent C then suggested that both the window and casement frames be slimmer in width and depth, he suggested 5 cm and 2.5 cm respectively. He also suggested that the shutters be only 1.25 cm in depth instead of 2 cm which would make the Metamorphic shutters rigid and withstand bending. The suggested modifications by Respondent C resulted in the constructed MS frame and drafts casement of being lighter than the conventional static shutters window. It was capable of being carried with 1 arm without any hassle and more importantly the cost was reduced by 100 EGP from 300 to 200 EGP including labor charges (See Figure 8).

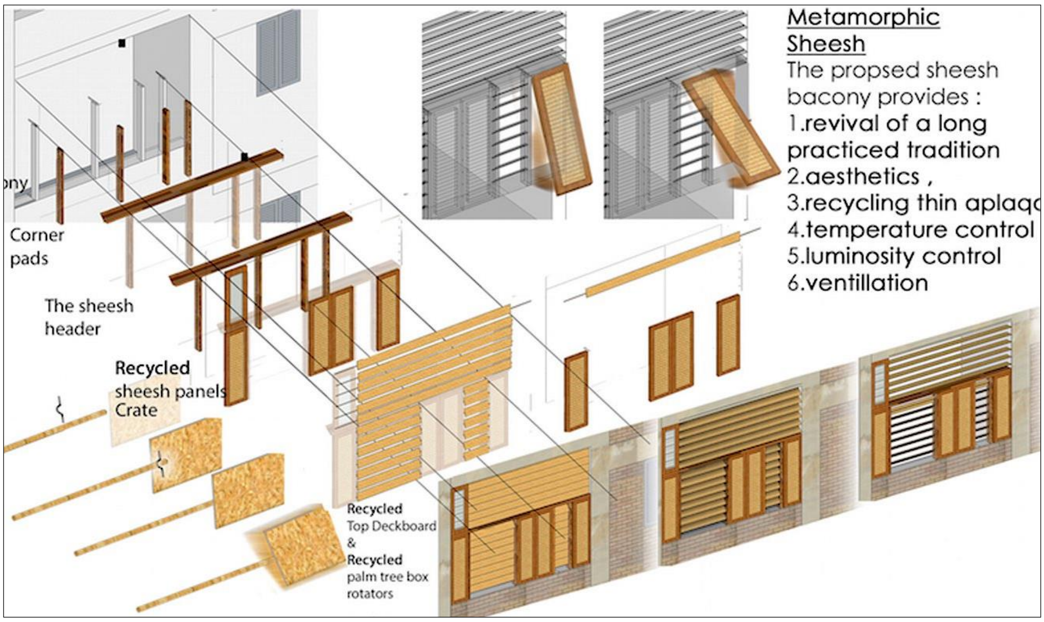


Figure 6. The figure shows the proposed metamorphic shutters at the concept stage presented at the UIC competition held in Cairo (Author, 2019).

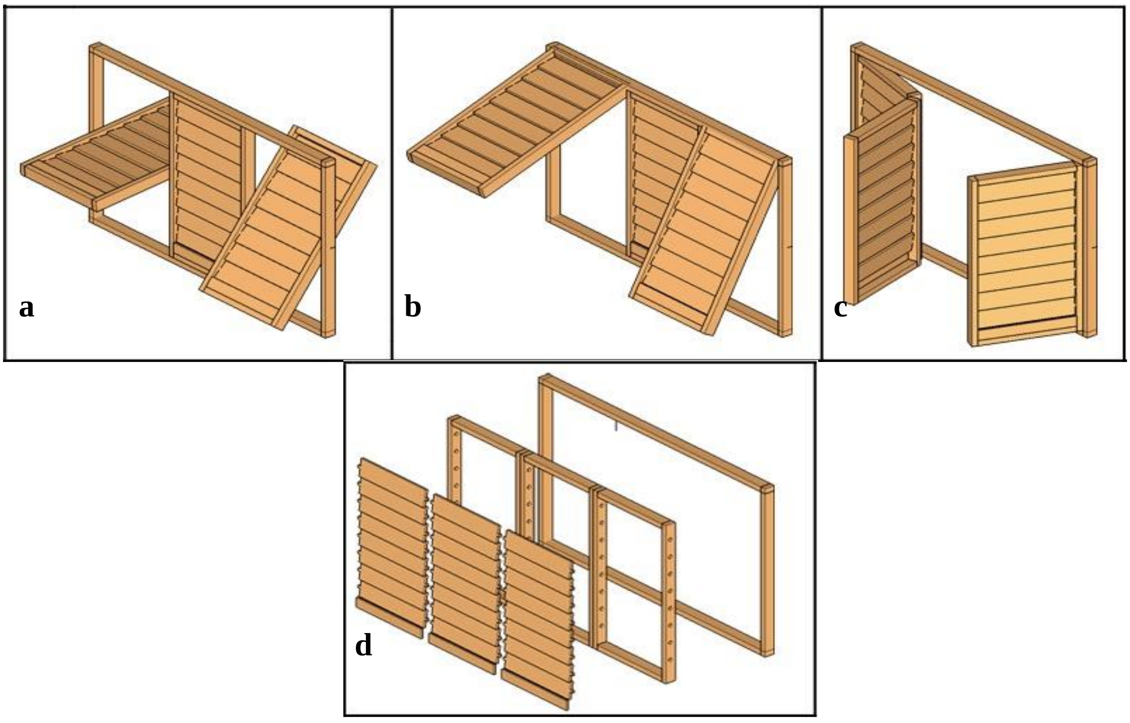


Figure 7.a, b, c, The figures show the renderings of the proposed modifications to the original MS design in (Fig. 6).

Figure 7.d. Shows the components of the MS in an axonometric diagram which are the window frame casement, the 3 drafts casements with grooves and the MS louvers (Author, 2019).

Figure 8. Photos of the MS installation onsite (Author,2017). The top 4 photos show the effect of direct lighting on the experiment room and the bottom 4 photos show the effect natural lighting on the experiment room. The bottom photo shows the MS from the outside of the building with the conventional shutters left wide open.

3.3. Quantitative results at the MS post installation stage

It is important to note that during the two times of the year which the readings were taken for a week by the author, the glass panels were closed from 12:30 pm to 4:15 pm ensuring the prevention of heat loss or gain through ventilation so as not to affect the resulting temperature difference results due to ventilation. The temperature readings were taken in the middle of the room using a digital thermometer whilst the lighting readings were taken at 1 m and 4 m away from the window and an average value was calculated, also 2 readings were taken consequently from the light meter at both measuring points followed by an average calculation to settle the fluctuating readings on the screen. Both the thermometer and light meter were placed outside of the window using an extension rod to take the temperature and light readings outside the room. For the lighting level readings.

3.3.1. Temperature results

During the winter, it was noted that the average ambient temperature of the experiment room was cooler than that of the control room by an average temperature range of 1.2 to 2.75 °C. The minimum temperature values for both rooms were 11.8 and 12.5 °C, and the maximum temperature values were 17.45 °C and 19.15 °C respectively.

However, in the summer, the temperature difference between the experiment room and the control room in the summer ranged from 4 to 7 °C, making the experiment room the cooler room. The minimum temperature values for the experiment and control rooms were 25.3 °C and 30.5 °C, and the maximum temperature values were 36.4 °C and 41.9 °C respectively.

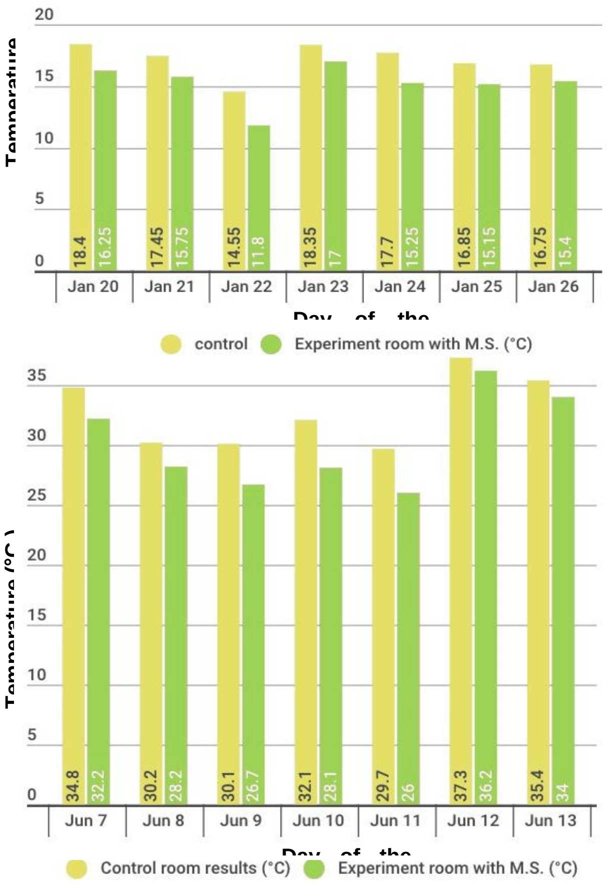


Figure 9. The figure represents the temperature outcomes for both the control room and experiment room during the hottest and coldest times of the year

3.3.2. Lighting results

The lighting results were extremely diverse in the winter. The MS window lighting results conferred to the standards set by the Lighting of work places — Part 1: Indoor (2005) for writing, typing, reading and circulation which are set at 500 lux, but only at 1 m distance from the metamorphic shutters at 4pm. However, this was not the case with any of the other 3 readings which were 1 m away at 1pm and 4 m away at 1 pm and 4pm. On the other hand the control room results were always 50 to 200 lux more than the required lux level at 1 m away from the window at 1pm and 4pm. However, at 4 m distance that was not the case. In general, the lighting levels in the experiment room had lower values throughout the week by 50 to 300 lux, with the experiment room sometimes showing half of the lighting levels that were present in the control room. The lowest temperatures in the experiment and control rooms were 87 lux and 213 lux, and highest temperatures were 1505 and 2305 respectively.

During the summer, the experiment room had high levels of lighting ranging from 500 to 1200 lux, but the control room had higher levels of lighting with values which were between 1000 to 2000 lux due to the entry of direct sunlight without any interruption. The lowest lighting results in the experiment and control rooms were 267 lux and 430 lux, and the highest lighting results were 1282 and 2014 respectively.

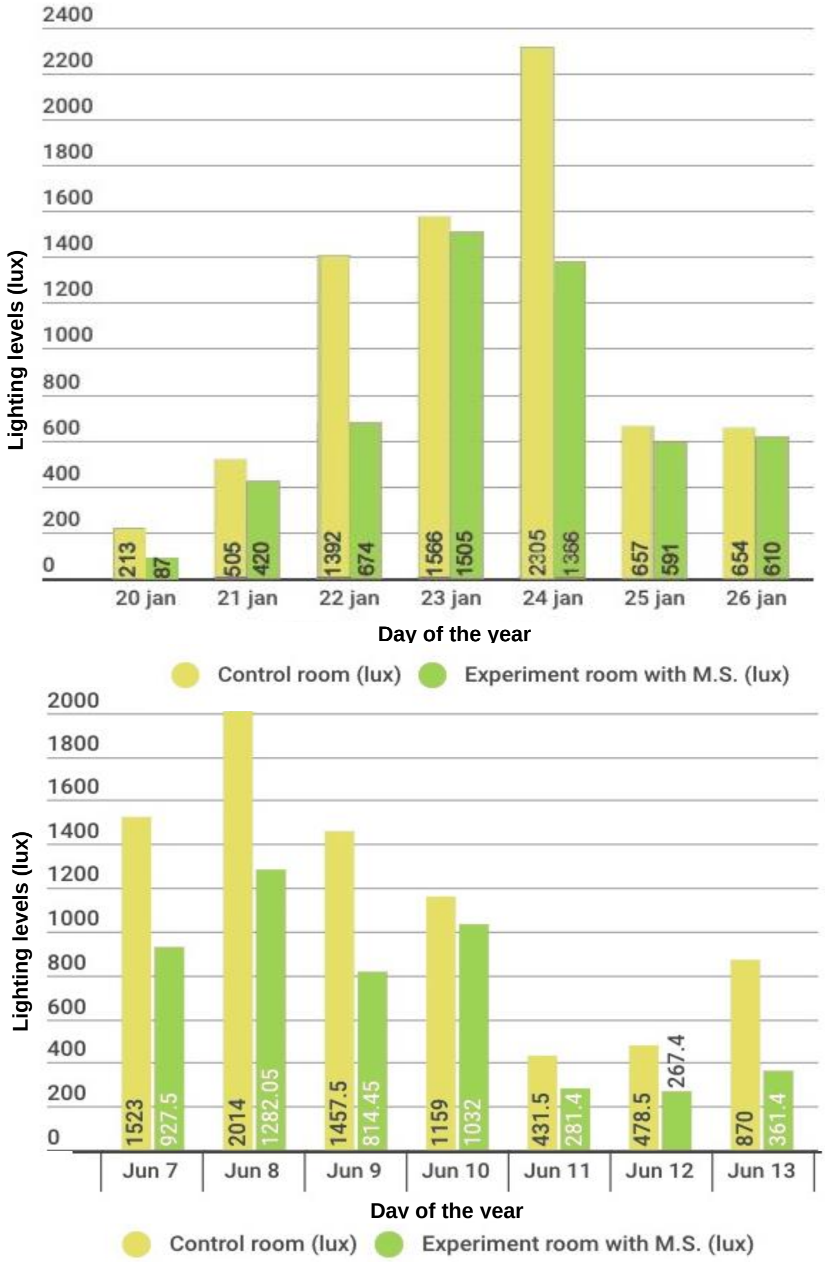


Figure 10. The figure represents the lighting outcomes in both the control room and experiment rooms in both the warmest and coolest times of the year.

3.4. Qualitative results at the post MS installation stage

A decision was made to leave Respondent A to test out the louver angles and change them to her convenience between the peak coldest and hottest times of the year whilst the author was not taking onsite measurements. This allowed for a much more extensive and deeper study of the MS through gaining qualitative information from the respondents.

The author provided colored marks and labels on the MS casement frames representing the needed angles for each month which would either allow for the maximum amount of direct light to either enter the room or to be obstructed according to the needs of the respondent for each month. This was done by comparing the incidence angles at each hour from 1 pm to 4 pm and an average angle was taken to either hinder or allow as much direct light as possible. This was crucial to ensure that the MS would serve their function for the respondents in the absence of the author. During the December 2016 to April 2019 period, the MS had angle tilt marks for maximum direct light penetration, and during the period of April 2019 to June 2019, the MS had marks for maximum direct light prevention throughout the day.

This also allowed the respondents to explore the untested capabilities of the Metamorphic shutters such as allowing ventilation from the top louvers by keeping them horizontally aligned, and also tested their capability to allow complete privacy from the street by keeping the louvers vertically aligned. They also needed to open the drafts freely to hang laundry, look on to the street and-occasionally-allow for maximum amounts of ventilation or light entry.

The residents of the flat with the experiment room stated that the MS were very helpful for providing various lighting levels and privacy, they also noted that the MS allowed heat to escape the room and a breeze to penetrate every now and then. The MS also proved efficient in maintaining the functional benefits of the conventional shutter drafts which were the ability to allow respondent A to hang the laundry, look at the street for social engagement and leave the drafts completely open for stronger levels of ventilation. The temperature differences were obvious to the respondents in the summer but they were not that tangible in the winter to the respondents. Respondent A was asked to what level would you rate the temperature difference the MS provided in both seasons, with 0 representing the weak temperature difference and 10 being the strong temperature difference? Respondent A stated "3 out of 10 for the winter and 9 out of 10 for the summer". Both respondents, A and B, commented on the usefulness of the of the lighting levels configuration through the colored marks for the self-use phase.

3.4.1. Temperature results

During the winter, Respondent A made clear that the presence of the MS showed how partially obstructing the direct sunlight gain would cause both a slight difference in temperature-making the experiment room cooler-and a major or minor difference in natural light making the experiment room slightly dimmer or almost half as bright as the control room. Although the MS installation caused a slight drop in the interior temperature when compared to the control room, this difference could have been much greater in the presence of classical shutters which almost totally obstructed sunlight penetration throughout the day. Respondent A commented on the temperature by stating that she did not recognize much of a difference in the temperature between both rooms. This could have partly been due to the fact that the difference was minute and also because the difference in temperature might have emerged slowly throughout the day making it unrecognizable to her.

During the summer though, Respondent A made it clear that the temperature difference between both rooms was extremely recognizable, and that the experiment room needed much less cooling and passive ventilation than the control room. "The stand-up fan was open from only 4 pm to 6 pm as this was the peak time for overheating to occur", stated respondent A. The control room however needed the use of the standup fan from 1pm to 2pm and also from 3pm to 6pm with the door kept open for heat loss which caused disturbance to whomever was occupying the room. She compared this to the experiment room and explained that its door did not have to be opened and that one could close the door for sleeping and seclusion when needed as the stand-up fan was sufficient

3.4.2. Lighting results

As for lighting satisfaction, Respondent A made it clear that throughout the winter months, from early November to late December, the experiment room did not have as much light as it used to before the installation of the MS stating that the experiment room portrayed high levels of lighting from approximately 11.45 am to 2 pm each day. This direct light could not enter for longer due to the building on the opposite side of the street (the West side) being too high and thus obstructing the direct light from reaching the room. Respondent A stated that she had to open 1 or 2 drafts in the experiment room to allow more natural light in to compensate for the lower lighting levels. However, she said that she ultimately preferred the sunlight in the experiment room as it was more than enough to see properly in order to carry out most of the activities which she would occasionally perform in the bedroom such as studying for the children whilst enjoying privacy through the MS from neighboring eyes, whereas the control room had too much light and did not provide any privacy making the gained direct light unnecessary. However, she did mention that she needed to turn on a light bulb every now and then in the experiment room when the light levels were not sufficient enough and privacy was needed even though the recommended tilt angles were in place.

The respondent only opened the drafts in the experiment room from 8 am till noon to allow for sufficient day light to enter in to the room. However, the drafts were left closed for the rest of the day with the recommended MS angle tilt to allow maximum sun light in, “I did this because not much light was needed in the afternoon period as it was usually a time for sleeping or resting and privacy was needed during those times as well as a minimum amount of daylight for reading with my children but not complete darkness”, explained Respondent A.

However, during the summer Respondent A made clear that the lighting levels between 11:30 am till approximately 2:30 pm were the highest in the experiment room despite the MS being tilted in such a way that allowed for daylight but prevented sunlight. She also made clear that the control room had very high levels of lighting throughout the whole day which were mostly unneeded except during the early morning from 8 am to 10 am and in the late afternoon from 6 pm to 7 pm. She said that during those times she usually opened the window casements to their fullest in the experiment room to allow the maximum amount of light in, but other than those given times the drafts proved very efficient in preventing direct sunlight whilst receiving sufficient levels of daylight.

3.5. Quantitative results after modifying the MS using reflective snack wrappers

Before the measurements for the winter lighting and temperature levels where taken during the peak coldest time of the year, the respondents were interviewed and made clear that they needed the MS to allow more light in to the experiment room than before. This provided sufficient time for preparation and for initial thoughts on how to develop the MS. Respondent A clearly stated that she would have preferred the MS to give more daylight throughout the day just as it was during the summer. A plan to use reused snack wrappers “metallized plastic” as natural light level multipliers was at hand. By inverting the snack wrappers and adhering them to the top and bottom of each louver, their reflective inner surfaces would reflect the light entering the experiment room thus providing higher levels of natural light. The experiment was executed between January 27th, 2019 and February 2nd, 2019 right after taking the measurements for the coldest weak between January 20th 2019 and January 26th 2019 before the installation of the snack wrappers. This was then carried out for the month of June as well by installing the wrappers and testing their results from June 14th, 2019 to June 20th 2019, after the hottest week in which the lighting and temperature readings were taken from June 7th to June 13th 2019.

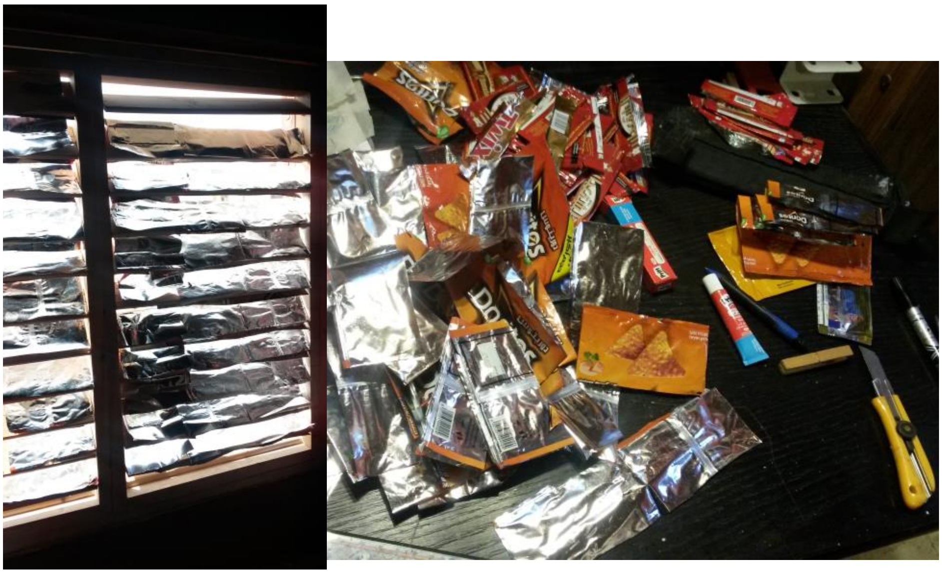


Figure 11. The figure showcases photos of the MS installation after the application of the reflective snack wrappers.

3.5.1. Temperature results

The temperature difference results between the experiment and control room were more or less the same as the results before the installation of the reflective wrappers for both summer and winter. However, in winter the average temperature differences were the same as the pre reflective wrappers installation phase for 3 days in the experiment room and differed on 4 days with a 0.2 °C to 0.4 °C warmer average temperature difference than in the pre installation phase of the wrappers.(Figure 12)

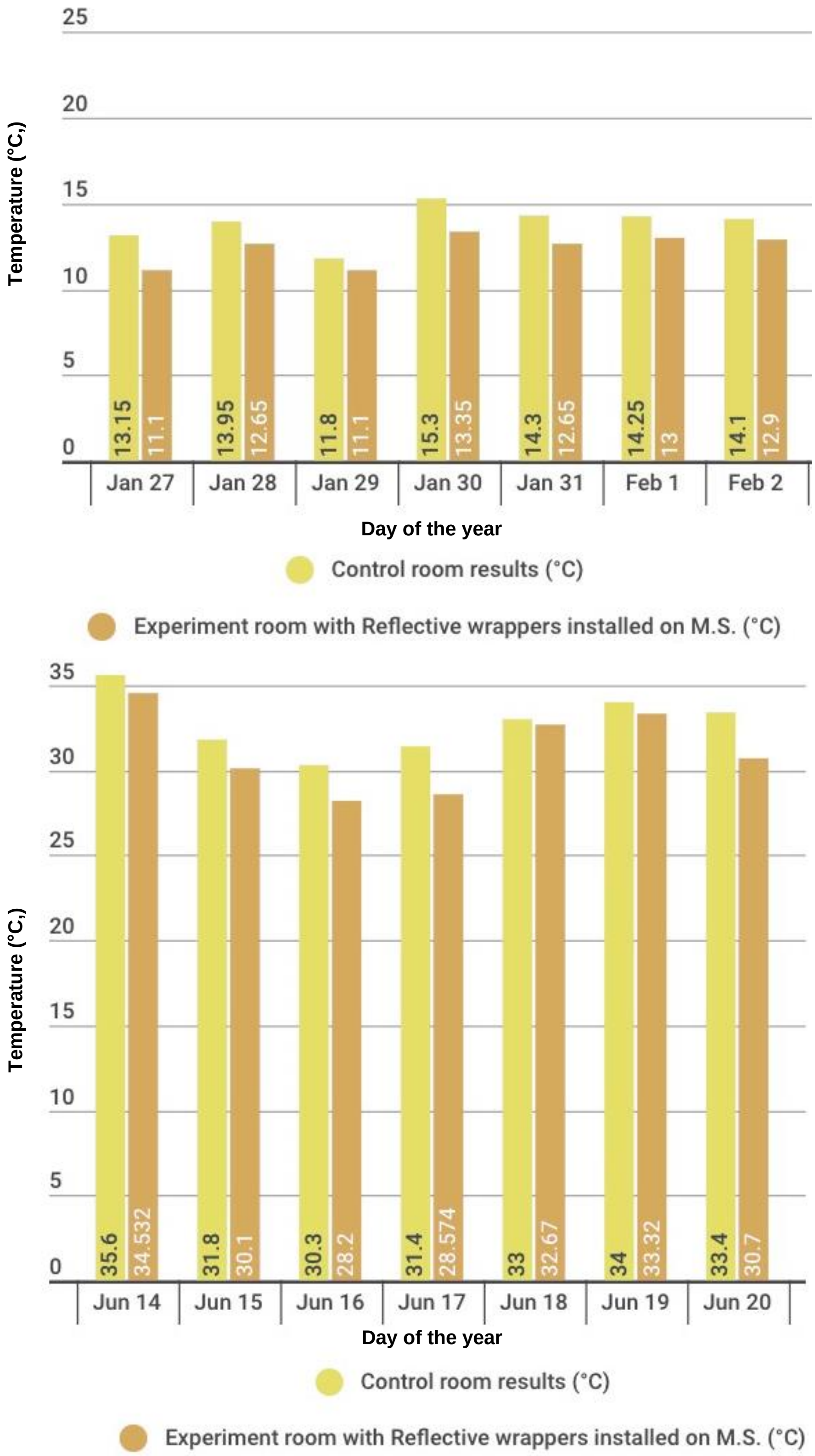


Figure 12. The figure represents the temperature outcomes in both the control room and experiment rooms in both the winter and summer after the installation of the reflective wrappers.

3.5.2. Lighting results

The results were surprising in that during the winter the experiment room day lighting levels (with the reflective wrappers on each louver installed) were above the control room lighting levels by a range of 70 lux to 700 lux with an average of 280 lux despite the absence of any shutters in the control room window. The measurements were taken at both 1pm and 4pm and an average value was then calculated. Although during the summer, the lighting levels of the reflective wrappers did not give the experiment room an advantage over the control room. In the summer, the lighting levels in the control room were higher ranging from 100 lux to 250lux with an average of 176 lux (Figure 13). A summary of the differences in results between the control experiment and the MS both before and after the installation of the reflective wrappers is presented in the table below (Table 1).

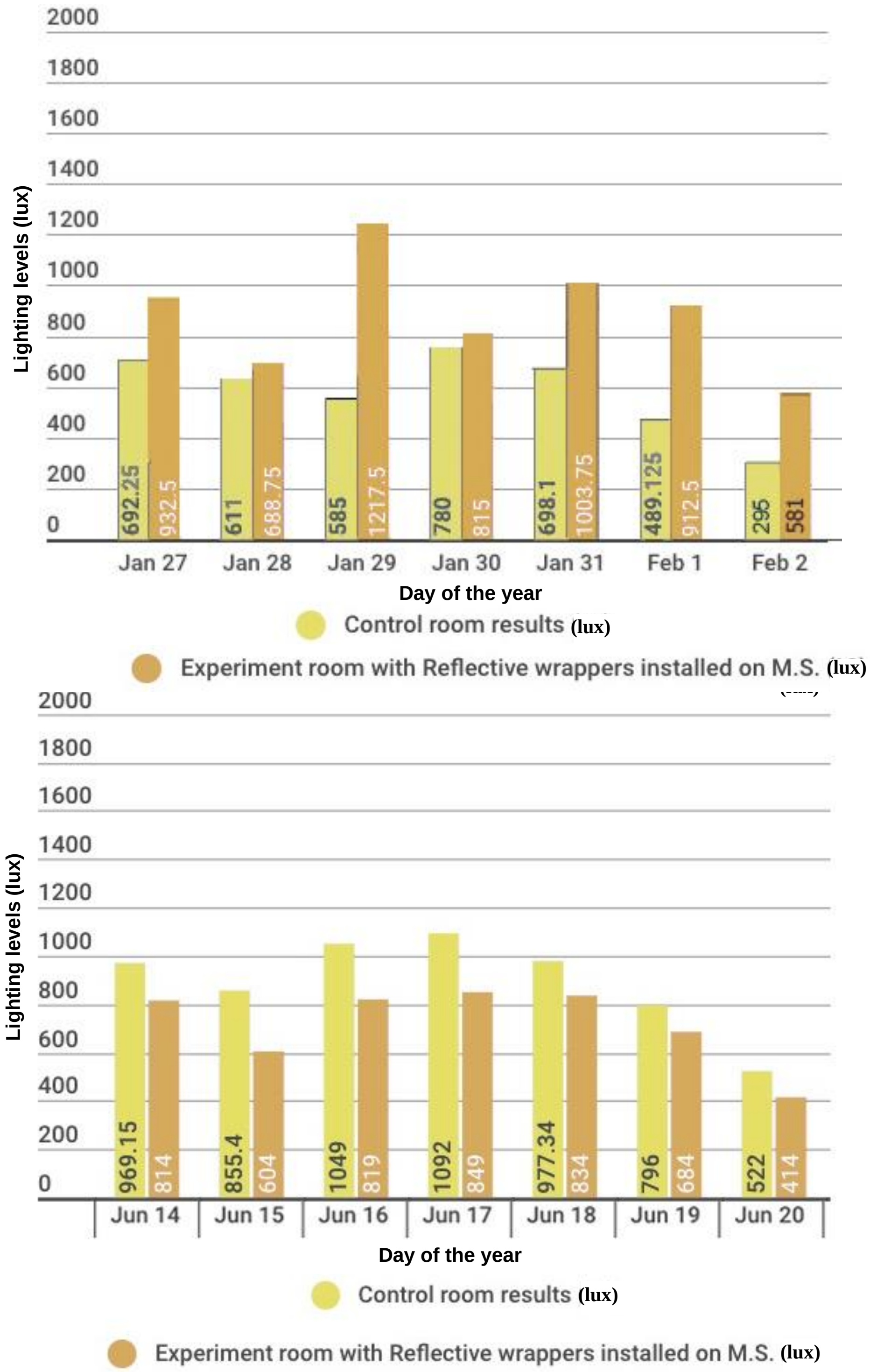


Figure 13. The figure represents the lighting outcomes in both the control room and experiment rooms in both the winter and summer after the installation of the reflective wrappers.

3.6. Qualitative results after the snack wrapper aluminum foil wrappers to the Metamorphic Shutters

Both respondents A and B experienced the MS with the reflective wrappers modification in February and August 2019 and then used them in their original form without the wrappers later on wards from March 2019 to the end of May 2019 and from August till September 2019. They made it clear that the natural light levels increased drastically during the installation of the wrappers installation, and this made trivial the need to open the drafts completely for light, although the overall experience of having the window void of the traditional shutters and of the MS in the control room seemed more comfortable in terms of them feeling more connected to the outdoors, as mentioned by Respondent A. The MS with the reflective wrappers also made the use of light bulbs unnecessary throughout the day whilst also providing full privacy, this was evident in the Respondents not having to switch on any lightbulbs or open any drafts to allow more light in. This was contrary to how the respondents had to switch on 1 light bulb from 1 pm to 4 pm in winter before the installation of the reflective wrappers to get enough light into the room. They were also bewildered by how the snack wrappers-which they always regarded as obsolete-proved useful in a way that they did not imagine before. A summary of the results are presented in Table 1.

Table 1. Represents the concluding average temperature and lighting differences between the Modified MS , the MS and the experiment room outcomes.

	Average Results Variations of the Metamorphic Experimental Shutters in respect to the Control room		
	Type of shutters	Temp. results (°C)	Lighting Results (lux)
Winter	Metamorphic Shutters	1.35 – 2.75 Cooler	44 - 939 Dimmer
	Modified Metamorphic Shutters	0.7 – 2.05 Cooler	35 – 633 Brighter
Summer	Metamorphic Shutters	1.1 – 4 Cooler	127 – 732 Dimmer
	Modified Metamorphic Shutters	0.4 - 2.9 Cooler	108 – 251 Dimmer

4. Conclusions

It is important to mention that this research has proven the intervention as a successful enhancer for thermal comfort levels during the summer but less so during the winter. The outcomes of the MS differed for each of the tested time periods in both temperature differences and natural lighting levels. They proved to be of practical use for the residents especially after the snack wrapper modifications were installed, making them more efficient and utilitarian to a certain extent.

4.1. Objective 1

The first objective was to quantitatively test the possible thermal comfort and lighting level outcomes of the MS by controlling the amount of direct light which enters the room. The results showed that the temperature differences between the experiment and control room in January and June were cooler by 1.35 °C to 2.75 °C and 1.1 °C to 4.4 °C receptively. The average lighting differences between the experiment room and control room were 44 to 939 lux and 127 to 732 lux respectively with the control room having higher results. The fact that the lighting differences in June were higher than the lighting differences in January and concurrently the higher temperature differences being in June than in January showed that an increase of daylight in spaces was correlative with temperature increase, and that controlling the amount of day lighting using the MS also meant controlling the thermal comfort levels however unmethodically.

4.2. Objective 2

The second objective was to qualitatively understand the end users subjective perception of the MS. Both Respondents A and B made it clear that the MS were functional in that they provided sufficient privacy and natural light synchronously. Their statements made clear that it was easy to maneuver the MS due to them being fixed but easily rotatable. Respondent A explained that them being installed in window drafts allowed the respondents to open the window drafts to allow direct sunlight in if needed just as their former window casement did but allowed for new and improved functions. Respondent C (the carpenter) was of the opinion that the MS could easily spread throughout informal settlement residents due to them being more practical than conventional shutters due to there louvers' larger sizes (making them easier to make and assemble), their lite weight, their conventional window casement drafts, their useful louvers and most of all their cost efficiency due to their slim wood cross sections.

4.3. Objective 3

The third and final objective was to test the MS after particular modifications were made to enhance the possible outcomes. Despite that the MS proved functional in terms of privacy, thermal comfort and the adjustment of direct light entry, they were also preventing sufficient amounts of day light to enter the experiment room occasionally. The reused reflective wrappers installed onto the top and bottom of each louver to multiply the natural lighting levels by means of refraction proved as an efficient solution for allowing adequate levels of day light in the experiment room whilst upholding the MSs' functionality of privacy provision but not so much in hindering direct light in this particular case. The increase of lighting levels in the experiment room during the winter after the wrappers' installation. had an average temperature increase of only 0.2 °C to 0.4 °C in the winter during most of the tested days. The modifications had a very subtle effect on the temperature differences unaffecting the thermal comfort levels, although the lighting levels were higher than they were in the absence of the snack wrappers.

4.4. Limitations

The temperature increase difference between the control room and experiment room after the installation of the reflective wrapper's modification could not be measured during the same dates in which the measurements were taken during the coldest and hottest weeks of the year. Although the dates are in close proximity being the week which followed the winter and summer measurements, this still does not replace the need to take the measurements at the same time during the coldest week of the year.

The equinox periods data could not be included in the research due to the sample respondent not being available during both equinox periods which would have contributed considerably to the research findings.

Due to the impracticality of visiting the 2 apartments arbitrarily on days with very cloudy skies, it wasn't possible to measure the lighting readings on random days throughout the year on days with cloudy skies to further test the capability of the reflective wrapper modifications and know whether they increased the natural light provision in the experiment room amidst cloudy weather conditions or not using accurate readings.

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