Passive Strategies for Buildings in Hot and Dry Climates: Optimisation of Informal Apartment Blocks in Cairo

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Abstract. Cairo’s dry and hot climate leads to challenges related to health, thermal comfort and energy consumption that its urban dwellers encounter daily. The informal apartment blocks in which most of the Cairene households live are generally poorly insulated against external heat gains, hardly shaded and poorly ventilated. Furthermore, especially during summer, about one-fifth of households experience constant power interruptions. This research shows to what extent it is possible, by using passive strategies, to optimise the architecture of informal apartment blocks, to meet the end user’s thermal comfort expectations while being energy and environmentally sound. By using Primero, an EnergyPlus based software, existing informal and traditional Cairenes buildings have been modelled, and thermal comfort and energy performance simulated and compared. Performance of informal buildings has been optimised and improved by using passive strategies. This has been possible by changing the structure of the building (adding an overhang), and by experimenting with the use of different materials for external wall constructions (all of which available in Egypt).

1. Introduction
Cairo, with its 18 million inhabitants, is one of the cities of the African continent in which the processes of urban transformation are more visible. With a population growth of about 2% per year – meaning that each year a city as big as Cardiff is adding up with its 360,000 inhabitants to Cairo - the city struggles to supply its inhabitants with adequate housing, urban infrastructure and energy without interruptions [1][2][3]. The city tries since years to distress the city centre and redirect its population towards new satellite cities (e.g. New Cairo), as well as to find solutions to deal with informality, the latter being still a significant characteristic in the pedigree of the Egyptian Capital, but still, there is much uncertainty about how effective and to what extent the situation is going to change for better.

About 65 per cent of Cairo’s urban dwellers live in informal settlements. The informal apartment blocks in which most of the Cairenes households live are generally poorly insulated against external heat gains, hardly shaded and poorly ventilated [2]. Thinking about Cairo’s climate, being hot and dry (BWh by Köppen-Geiger climate classification), it is deductible that living in reinforced-concrete skeleton buildings with external walls filled with one layer of 12 centimetres fired bricks affects the thermal comfort of its inhabitants negatively.

Most of the people that are not affected negatively by this – a tiny minority – are the ones that can afford to buy and run mechanical ventilation. As reported by the Ministry of Electricity and
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Renewable Energy in 2015, the residential sector in Egypt is responsible for about 44 per cent of the share of energy consumption (64,546 GWh). This number, which is also consistently growing, is due both to the “expansion of residential compounds [...] and the widespread use of domestic appliances, especially the air conditioners in the summer” [4][5].

This paper aims to give an insight into the research done at the REAP faculty of the HafenCity University Hamburg in which contemporary and traditional (and vernacular) buildings in different climates are studied and analysed, and thanks to energy performance simulation, they are optimised to increase end-user thermal comfort while decreasing energy consumption. This is the third paper that summarises results obtained with buildings in Cairo. The first paper focuses on the indicator for passive optimisation as well as a method for optimising the performance of a building (Passive adaptive strategies and indicators for the optimisation of comfort and energy demand in buildings in hot climates, [6]). The second one focuses on materials and thermal mass that are adequate for Cairo’s climate (Optimised external and internal constructions in buildings in hot and dry climates to support thermal comfort without air conditioning, [7]).

This paper has the goal to show the thermal performance of buildings built in Cairo and the potential for optimising them by using passive strategies. After having explained in detail the methodology used, in the chapter Simulation and Performance 18 rooms found in five informal buildings and one traditional building that was built by Hassan Fathy following traditional strategies have been analysed, and results on thermal performance are given. In the chapter Optimisation of Informal Buildings and Results, four rooms have been optimised to see to what extent it is possible to increase thermal comfort while reducing energy consumption only by using passive strategies. In the last chapter Discussion and Conclusion, the outcomes of this research are discussed as well as the further research that should follow up to have a holistic view of the matter.

2. Methodology and Assumptions

2.1. Simulation Process and Assumptions

The purpose of this report is to examine the thermal performance of 18 rooms in buildings found in Cairo, Egypt, modelled in Primero, an EnergyPlus based software that, based on room characteristics and usage, delivers hourly information about indoor temperature, comfort and energy [8]. There are two distinct categories of rooms analysed: informal and traditional ones. The five informal buildings were taken from a series of case studies researched by the Eidgenössische Technische Hochschule Zürich [9], and the traditional one is a building designed and built by Hassan Fathy. Rooms selected for analysis focused on Cairo, Egypt; thus, the geographic and weather file selected was for the same region. From here, the floor plans were measured using computer software, and the measurements of the room and components were put into Primero so that the room could be analysed. Several assumptions were necessary to develop a working model. The followings are the constant assumptions for all the buildings:

- Rooms modelled with the usage of ‘residential (bedroom) profile
- Usage is 6935 hours per year (19 hours/day)
- One or two external sun-exposed walls and no external shading from surrounding buildings
- Cross-Ventilation possible at up to 3 air changes per hour
- Single glazing window with internal roller blinds
- Shading control on blinds-closed when sun shining on façade
- Low equipment and lighting loads
- Internal constructions and obstructions modelled adiabatically
- Artificial light (on/off) according to daylight access
For all internal walls and barriers, adiabatic conditions were assumed. The short-coming in this assumption is that it expects all adjoining rooms (especially those without exterior exposure) to have the same temperature. In reality, there is a temperature difference between rooms, which could increase or decrease the overall comfort in the desired room. The process for Cross-Ventilation at various temperatures is a necessary assumption, as well as an understanding of the limitations on how Primero calculates temperature. This is done through a 1D-steady state flow, where air changes (rather than volumetric pressures) are simulated based on a typical user behaviour; below 10°C windows are closed, between 10 and 20°C windows are more and more opened, 20 till 39°C windows are fully open (maximum air change), above 39°C windows closed to avoid that external heat comes in. There were some specific assumptions necessary to model the informal rooms. Based on preliminary research, each of the informal rooms had the same building envelope composition: structural steel-reinforced concrete with fired brick infill. Since research indicates that most builds are five to eight floors, with the ground floor primarily used for commercial purposes, the rooms modelled were modelled above ground height. Additionally, the rooms modelled from buildings by Hassan Fathy – that follow traditional principles - have specific assumptions that should be outlined clearly (footnote 4). Based on literary information, it was assumed that all the constructions would have a uniform envelope composition, with adobe as a basis. The only difference from model to model was the thickness of the walls, which was derived from the architectural drawings. Although many of his buildings feature no glazing, or more traditional wooden structures, to get comparable results, the standard glazing assumption was used as the parameter in each of the constructions. When north was not provided on the drawings, it was assumed based on building orientation.

2.2. Indicator and Optimisation Process

The following sections summarise the methodology for “Indicator Topt” and optimisation strategy, which was previously published [6][7]. Passive buildings are optimised to reach thermal comfort using only passive systems. In a climate like Cairo’s (Hot and Dry) it is a challenge to design such buildings in which the operative indoor temperature (Top) is always below outdoor temperature as well as also below the comfort temperature (Tcomf) – in our case set at 28°C. As shown in figure 1 the indicator Topt counts exceeding hours in which Top>Tcomf only in case of insufficient passive optimisation, therefore, only if the indoor temperature (Top) exceeds outdoor temperature (Te). Topt is determined at all hours of use and summed up to a yearly value in Kelvin hours (Kh). By dividing Topt by the number of hours the room is used (in our case 6935) a yearly average in Kelvin is generated (Toptw). To keep comfort – as a rule of thumb – the difference between Top and Te should not exceed 1 K. The results exceeding this threshold, are considered an opportunity for optimisation.

Figure 1. Visualisation of Topt (potential of passive optimisation). (a) indicates the situation in which Top and Te are above Tcomf, and Top is above Te (Top>Tcomf; Te>Tcomf; Top>= Te). (b) indicates when Top is above Tcomf and Te is below Tcomf (Top>Tcomf; Te<Tcomf). [6]
The optimisation strategy used follows the basic rules that are required when building in this kind of climate. First, priority is given to the reduction of solar heat gains (by shading windows and facade, and adding a window screening with the optimal grade of transmissivity), then priority is given to heat removal (different ventilation strategies as well as by optimising the building envelope). In this paper, the phases of optimisation are visualised to simplify the readability as well as to understand which phases are the most important for thermal performance.

3. Simulation and Performance

3.1. Characteristics of Buildings

Especially thinking about the buildings built from the seventies on - thanks to the Egyptian economic boom – there is a typology that covers almost 90% of all dwellings in Cairo: the multi-story apartment block. These are reinforced-concrete skeleton buildings with walls filled with one layer of 12 centimetres fired bricks (figure 2). On average, they are five to eight floors high - but can reach exceptionally more than 15 [1][2] While all floors above the ground are residential, typically on the ground floor commercial activities take place. Due to the high built density, most of the buildings have only one exposed façade. Ventilation, as well as light, for rooms situated in the centre of the building is possible through shafts – a typical element that can be found in Old Cairo or or 19th-century buildings [9]. Traditional buildings on the other way, are more difficult to be found in Cairo, and depending on the age they have, they can be traced back to Pharaonic, Islamic, Ottoman, as well as Colonial periods. Hamed Said building, built in two phases between 1942-1945 by architect Hassan Fathy, is one of the buildings that tries to show the legacy to traditional Islamic architecture, be it by choice of materials, or the design itself. The floorplan evolves around a central courtyard in which high trees find their space. Construction is massive with thick walls in adobe and small windows. Most of the ceilings are domes, and apart from corridors and a gallery that are to find around the courtyard, all rooms have at least one exposed wall [10].

**Figure 2.** Left: simplified floor sections of informal (a) and traditional building (b) based on [9] and [10]. Right: external wall constructions used in the optimisation (Phase 3, Chapter 4).

3.2. Performance of Existing Buildings

Table 1 summarises the results of the simulations on the 18 simulated rooms. Across the rooms modelled, there is a wide range of values for comfort metrics. The immediate cause for the differences is not evident. Nevertheless, this is what can be observed:

- Most of the rooms have a Toptw below the threshold of 1 Kelvin. Only two rooms exceed the threshold of 1 K.
- Five rooms in three buildings have a Toptw below 0.16 Kelvin (Rooms 1, 2, 3, 4, 5).
- The best buildings are comfortable >75% and the worst buildings are comfortable < 50%.
- The only room in a traditional building has a Toptw below 0.5.
- When grouped by [K] 0.10 bins, the height of the room has a direct relationship with the comfort metrics. As of height increases, comfort increases.
- The larger the surface area of the floor plan, the higher the overall performance of the room.
The primary outcome of this part of the analysis shows that some of the most apparent correlations are the ones between Toptw and either the height or the surface area of the floor plan. We have been looking at correlations with the orientation of the room, as well as the importance of having a window on the façade or a shaft, and we realised that more research should be done on that matter – at least with the set of buildings and rooms we have at disposal. When looking at differences in the performance between a traditional and an informal design, we can observe that the room number 8 performs within the best 50% of the analysed rooms.

Table 1. Rooms Characteristics and Simulation Results (as Built).

| Room Nr. | Building Name | Area [m²] | Height [m] | Window Area [m²] / Sun Exposed [V/N] | Sun Exposed Window Area / Area of Usage [ratio] | Sun Exposed Walls (Nr. / Orientation) | Topt [K] | Toptw [K] |
|----------|---------------|-----------|------------|------------------------------------|---------------------------------|-----------------------------------|---------|----------|
| 1        | Mahmoud’s     | 29.0      | 3.3        | 1.25 (Y)                           | 0.04                            | 1 (S)                              | 559     | 0.08     |
| 2        | Hanaa’s       | 28.1      | 3.0        | 1.5 (Y)                            | 0.05                            | 1 (S)                              | 697     | 0.1      |
| 3        | Mahmoud’s     | 48.6      | 3.3        | 1.25 (Y)                           | 0.03                            | 1 (N)                              | 699     | 0.1      |
| 4        | Kadry’s       | 16.0      | 2.9        | 1 (N)                              | 0.06                            | 2 (E & S)                          | 1007    | 0.15     |
| 5        | Hanaa’s       | 16.1      | 3.0        | 1.5 (Y)                            | 0.09                            | 1 (S)                              | 1066    | 0.15     |
| 6        | Hanaa’s       | 20.2      | 3.0        | 1.5 (N)                            | 0.07                            | 1 (W)                              | 2482    | 0.36     |
| 7        | Hanaa’s       | 19.4      | 3.0        | 0.0                                | 0.0                             | 1 (S)                              | 2599    | 0.37     |
| 8        | Hamed Said    | 11.3      | 3.2        | 1.45 (Y)                           | 0.13                            | 1 (S)                              | 3188    | 0.46     |
| 9        | Hanaa’s       | 15.8      | 3.0        | 0.0                                | 0.0                             | 1 (N)                              | 3690    | 0.53     |
| 10       | Mahmoud’s     | 18.9      | 3.3        | 1.25 (N)                           | 0.07                            | 1 (N)                              | 3980    | 0.57     |
| 11       | Hanaa’s       | 12.3      | 3.0        | 0.0                                | 0.0                             | 1 (E)                              | 5315    | 0.77     |
| 12       | Abdullah’s    | 14.4      | 2.8        | 0.0                                | 0.0                             | 2 (N & E)                          | 5584    | 0.81     |
| 13       | Hamdy’s       | 27.3      | 3.0        | 0.0                                | 0.0                             | 2 (N & E)                          | 5922    | 0.85     |
| 14       | Abdullah’s    | 14.4      | 2.8        | 1.33 (Y)                           | 0.09                            | 2 (N & W)                          | 6603    | 0.95     |
| 15       | Hamdy’s       | 34.3      | 3.0        | 3.0 (Y)                            | 0.09                            | 2 (E & S)                          | 6621    | 0.95     |
| 16       | Kadry’s       | 16.0      | 2.9        | 1.4 (N)                            | 0.09                            | 2 (N & E)                          | 6897    | 0.99     |
| 17       | Hanaa’s       | 19.3      | 3.0        | 0.0                                | 0.0                             | 2 (N & E)                          | 6953    | 1        |
| 18       | Kadry’s       | 11.8      | 2.9        | 1.41 (N)                           | 0.12                            | 1 (W)                              | 9384    | 1.35     |

Informal Building / External walls in fired bricks (12 cm) [no background colour in table]
Traditional Building (Grey) / External walls in adobe (60 cm)
Informal Building used for Optimisation in Chapter 4 (Dark Grey) / External walls in fired bricks (12 cm)

To generalise conclusions, more buildings should be included in the set 4. With an increased number of modelled rooms, it may become clearer what can be sources of such results. While there are definitive parameters, such as building envelope composition and external shading, that improve the room profile, it is not currently clear yet – out of simulations - if there is a noticeable difference in comfort between the informal buildings and those designed by Fathy.

4 Added to the selected traditional building, two other buildings designed by Hassan Fathy – and that follow traditional passive strategies - have been simulated, namely the Shri Zaher Building and Carr Building (two rooms each). Including Hamed Said Building, all traditional rooms performed in the top half of the overall table. They were not shown as part of the results because they are not in Egypt.
In Phase 01 the same assumptions are made as in Chapter 2.1. Both buildings share similar characteristics: each building has a room without window (the one oriented towards North-West), has one room with external walls facing North and East, and has one room with external walls facing North and West (with window). The main differences can be seen in the size of the rooms and windows. Hamdy’s building rooms have about the double of the room surface as Abdullah’s, and the window has most of the double of the surface than Abdullah’s.

As can be seen in figure 3, for each room, three extracts of results the different phases of optimisation are shown. While in the first two phases the three results are identical (Phase 01 is the status quo with the standard construction, in Phase 02 the reduction of solar gains is obtained by adding an overhang) the difference between the three results are due to the last phase of optimisation (external wall construction). Here, even though we have simulated 12 different external wall constructions, we have decided to show results of materials that are either traditional (adobe), or that can be found in Cairo (bricks, aerated concrete, polystyrene). As we have explained in Chapter 2.2, there are still two optimisation processes that could take place: in Phase 02 the optimisation of grade of transmissivity of the window, and between Phase 2 and 3 the optimisation of the ventilation strategy.

Regarding the grade of transmissivity of the window, we realised that by adding a screen in front of a window, the performance is not increasing – at least with the two analysed rooms with a window. Previous simulations show that with the room having another orientation (window towards South façade) a window screen can increase the performance ([6]). Concerning the optimisation of the ventilation strategy, since simulations done for status quo implied already cross ventilation possible whenever needed – in other words, best case possible –, no results showing other ventilation strategies are shown.

The first thing we can easily observe by looking at the status quo is that the rooms that receive fewer heat gains during the day (room 12 and 13) are the ones that in Phase 01 perform better than the other two. This is because first, they have no windows, and second, they face East – meaning that they get solar heat gains only during the morning.

For Phase 02, different overhang depths were simulated for each room. The best result in Toptw, have been reached by dimensioning the overhang as it follows: Room 12 with 1.75 meters, Room 14 with 2 meters, Room 13 with 1.45 meters, Room 15 with 2 meters. To note: both rooms facing West, measure 2 meters. By looking at results after having dimensioned the external shading, we see that by keeping away direct sun radiations from the façades, it is possible to increase the room performance in

![Figure 3. Simulation and visualisation of results (Topt) of four rooms at different stages of optimisation. The numbers in the coloured bars show the percentage of optimisation related to the status quo (Phase 01).](image-url)
a range between the 30 and 37 per cent. Moreover, it is precisely by looking at the rooms that are more exposed to sun radiations (room 14 and 15) that it is observable the highest improvement with results of around 37 per cent.

After Phase 03, by changing the external wall constructions, the highest percentage of performance improvement is to be found in rooms 12 and 13 – with a range of between 51-59 per cent of improvement from the previous phase, while the rooms 14 and 15 gain between 36 - 49 per cent. Most probably, the situation is due to the windows as well as the window to wall ratio. Room 15 - with a bigger window - is the one that, even though is performing well, has got the lower increase in optimisation.

Looking at external wall construction of the four rooms a clear trend is noticeable: while adobe (36 cm depth) is consistently performing well – as well as fired bricks with polystyrene (24 + 5 cm) - a construction wall of 24 centimetres aerated concrete with the addition of 5 centimetres’ polystyrene is the one that of the three performs best. This is due to the highest U-value as well as the thermal mass of the construction [7].

5. Discussion and Conclusion

Cairo’s dry and hot climate leads to challenges related to health, thermal comfort and energy consumption that its urban dwellers encounter daily. This is also due to the apartment blocks in which most of the Cairenes live; they are generally hardly shaded, poorly insulated against external heat gains and poorly ventilated.

In chapter 3.2 Performance of Existing Buildings this has been partially confirmed by the simulations that were done on 18 buildings. Two buildings have a Toptw exceeding 1 K (meaning that on average the operative temperature is 1 K higher than comfort temperature or outdoor temperature). Eight buildings are in the range of between 0,5 – 1 K, and the best-performing ones find themselves in a range between 0,08 and 0,5 K. Part of the analysis indicates that there are correlations between Toptw and either surface area of the floor plan or room height. Added to that, potentially (footnote 4), traditional buildings find themselves within the best performing one. There are definitive parameters, such as building envelope composition and external shading, that improve the room profile. Nevertheless, due to the number of other room’s characteristics that play a role in thermal comfort (e.g. orientation, windows, window to wall ratio, connection to a shaft) more research and a broader dataset are needed to make a general conclusion.

In chapter 4. Optimisation of Informal Buildings and Results, an optimisation strategy that focuses first to reduce heat gains and then to remove the heat has been used. By following this strategy, it has been possible to increase thermal comfort by an average of 80%. In the best case by reducing Toptw by 0,83 K (Room 14). In the worst case (Room 15 – facing West, with an exposed window area of three meters) by reducing Toptw by 0,73 K. This has been possible especially by changing the structure of the building – adding an overhang, and by experimenting with the use of different materials for external wall constructions (adobe, bricks, aerated concrete, polystyrene - all of which available in Egypt).

With this research, it was possible to demonstrate with digital model simulations to what extent – and in which range - it would be possible to optimise the thermal performance of informal buildings by using passive strategies only. The methods used for doing this has proven again to be effective, and, when thinking about the time needed to get results, it has also proven to be efficient [6] [7].

Nevertheless, questions regarding correlations and comparison of different rooms remain partially unanswered. We have already some hints about windows size, orientation, size of the room and windows to wall ratios. However, probably, a bigger and diverse dataset together with simulations done on a building scale (building simulation), could help to find out how the geometry of rooms and buildings can be improved, as well as to find out what are the “no go” in this climatic condition. Such work could also help to understand differences between traditional and contemporary buildings, and it would be helpful especially to learn how the traditional passive strategies could be applied in
contemporary and informal architecture while meeting the needs of end-users that generate this kind of architecture.

While thinking further about the improvements in the performance of buildings, this research also raises new questions that need an answer. *How could be such improvements integrated into the Cairenes building culture?* would be an important one. However, inevitably, before answering questions that look at the implementation of strategies only, questions that look at a sustainable future should be addressed. Assuming that all means have been found to improve the performance of buildings, what would be the consequences of such interventions when we think about social acceptance and economic power of informal settlers, for example? We know how important are social structures, as well as that most of the people living in informality are also weaker in terms of economic power. So, how could we integrate this new knowledge to be accepted and implemented with the economic means at disposal without becoming a burden? Also, what would be the consequences by improving performance in buildings related to the ecological dimension? If we are going, for example, to use materials such as polystyrene in informal buildings – for the one hand side we would increase the thermal performance of buildings, but on the other side, we would generate a problem related to disposal and recycling that right now is not there.

We remain sure, that the most innovative solutions that can be found in the field of building performance and building efficiency, if thought and implemented using sustainable principles, can lead to an improvement to health conditions, as well as responsible use of resources and energy.

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