

442: 7 Fountains Primary School Post-occupancy Evaluation

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Abstract

7 Fountains Primary School is situated in an impoverished community with extreme climates in the Kokstad region of KwaZulu Natal, South Africa. The new school was built with passive design principals to provide a healthy, comfortable learning environment. This project sought to quantify the performance of these passive interventions. In a collaborative effort with the school's educators and staff, a number of data sensors, consumption meters and a weather station were installed at the school. Overall the classrooms are 10°C warmer in winter than outdoor temperatures, the light levels are significantly high such that electrical lighting is seldom used and innovative water systems have provided 45% of the toilet block water from non-potable sources. Insulated cavity walls provide improved thermal performance and traditional mud-brick construction provides moderate indoor surface temperatures despite extreme outdoor surface temperatures. Donated facilities such as computers that low-income schools do not usually have access to, demand an additional 39% electricity. Teachers have noticed a drop in winter absenteeism from 50% in the old school to almost 0% in the new school. The data is being used to inform design decisions about other rural school projects.

Keywords: passive design, monitoring, schools

1. Introduction

7 Fountains Primary School opened in 2007 in Shayamoya, a poverty stricken settlement outside of Kokstad, Kwa-Zulu Natal, South Africa. Kokstad experiences extreme weather conditions relative to the rest of South Africa; including snow in winter and high temperatures in summer. Figure 1 shows the maximum, minimum and mean dry bulb temperatures throughout the year.

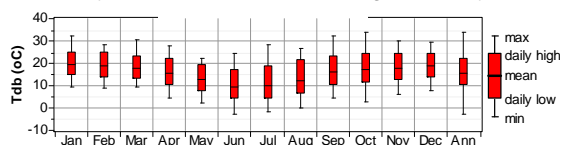


Fig 1. Dry bulb temperatures for Kokstad

The school buildings were built with external donor funding but within a conventional Department of Education budget. This enabled the design to stray beyond the standard educational design drawings while still making the various interventions obtainable to other projects. Effort went into using passive-design principals to optimise comfort and extensive workshops with the local community ensured public input. Passive design strategies included daylight analysis, natural ventilation, thermal performance of the building envelope, and thermal comfort in the classrooms. Conservative energy and water systems were also installed to minimise reliance on municipal supply while still providing a healthy teaching environment.

This paper explores the post-occupancy performance of the school and in particular the performance of certain passive design strategies. In a collaborative project with the educators at the

school, a number of data logging devices were installed to monitor different aspects of the design and function of the buildings.

Qualitative investigation provided feedback on the perceived comfort of the learners. The results from this investigation are valuable for future design decisions at other schools with the results being freely disseminated.

2. Daylight

The 1990s saw a resurgence in designing schools with good daylighting. Not only does this reduce energy consumption from artificial lights, but a number of studies have shown the strong correlation between improved student performance and daylighted schools. Niklas and Bailey [2], in a study on three daylighted schools in North Carolina, showed that students at these schools outperformed their contemporaries in non-daylit schools by 5-14%. Hescong et al support this finding with a further study in the United States involving 3 districts of 6000 – 8000 students each in which they “established a statistically compelling connection between the presence of daylight and student performance” [1].

While the exact reason for this connection is unsure, studies [1, 3, 4] suggest that increased daylight provides better visibility, enhanced mood and improved health.

2.1 Design strategies

The 7 Fountains design resulted in 70% of teaching spaces having optimal orientation (North facing) for classrooms with walkways on the South side to avoid over shading in winter. Light shelves made of galvanised metal assist in solar

shading and reflect light onto the light coloured ceiling and deeper into the space. Blackboards are positioned on the South side of the classroom to avoid glare from the large North windows. In an attempt to reduce electricity consumption by breaking habit of turning all the lights on at once, the electric lights switch on separately: the lights on the darker side of the room are connected to a switch at the door and the lights on the lighter side of the classroom are connected to a switch near the windows (opposite the door as in figure 4).

2.2 Measurements

Light sensors were installed at occupant level in the following classrooms:

- Optimal North facing orientation at 7 Fountains
- Sub-optimal West orientation at 7 Fountains
- Optimal North orientation at conventional local primary school

In the North facing classroom at 7 Fountains, state loggers were installed at the light switches to determine when lights are turned on and off.

2.3 Results

Light levels at 7 Fountains are consistently high even in classrooms with sub-optimal orientation (figure 2). In the week shown, electric lights were only used on the 21st April. The conventional local school, with no access to electric lights, has significantly lower natural light levels, despite its Northern orientation. The solar radiation, indicative of outdoor light levels, is given in the figure to show the relationship between internal and external light.

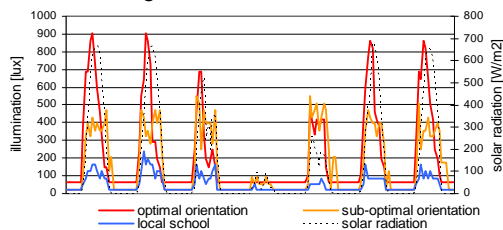


Fig 2. Comparison of light levels in classrooms with optimal/sub-optimal orientation, and a conventional local school; solar radiation included: 17 – 23 April 2008

Figure 3 shows the results from the state loggers at the light switches during the summer rainy season. The electrical lights are seldom used and only at times when the average light intensity is low. This is confirmed by the survey data in which educators explained that they only use electric lights during overcast or cloudy conditions [6].

The bar chart shows the duration of electric light use on the dark and light side of the classroom indicating that the lights on the dark side of the classroom are used more frequently than the lights on the lighter side. This trend is more pronounced in the latter part of the time period. This could be attributed to the instructive posters (figure 4) that were installed in the classroom in February 2008 explaining the measurement

devices and how lights should be used confirming the importance of occupant education.

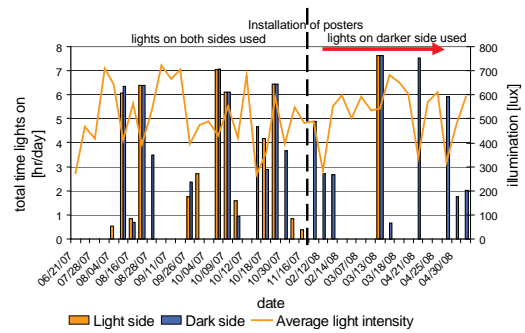


Fig 3. Duration of electric light use on light and dark side of classroom; with average light intensity

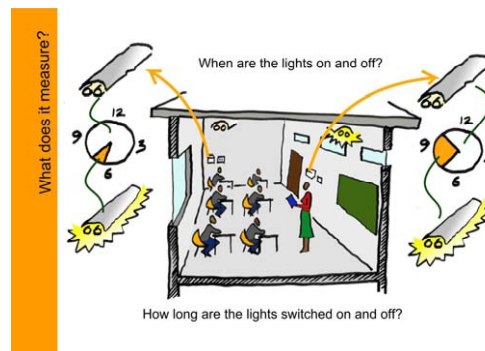


Fig 4. Poster installed in classroom explaining measuring equipment and separate switches

3. Temperature

Thermally comfortable classrooms with adequate ventilation play an important role in effective learning. In a survey with the educators at 7 Fountains Primary School, it was noted that in comparison to the poorly insulated previous school building, absenteeism during winter has dropped from 50% to almost 0%. They suggest the reason for this is that the classrooms are more comfortable than the children's homes [6]. Improved thermal performance, increased natural ventilation and fewer learners per room has provided a healthier environment where the risk of illness is reduced.

3.1 Design strategies

Given the extreme climatic conditions experienced in the Kokstad region, particular attention was paid to thermal comfort within the classrooms. The old school buildings (converted migrant worker cottages of concrete blocks with no ceilings) had very poor thermal performance [6]. Optimising orientation for most classrooms and putting the walkways on the south side of the buildings provides opportunity for passive solar heating.

The architects and designers of 7 Fountains Primary School substituted Department of Education specified bricks for locally manufactured bricks. Not only did this provide much needed capital injection into the local community and reduce the negative environmental impacts of additional transport, but

it also freed up funding for installing insulation in the cavity walls.

The ceilings are insulated (u-value of 0.4W/m²K) which improves thermal performance through reducing heat loss in winter and heat gain in summer. It also improves comfort levels by reducing the fluctuation in mean radiant temperatures of an important surface exposed to the occupants.

3.2 Measurements

Temperature and humidity loggers are installed in optimal and sub-optimally orientated classrooms at 7 Fountains and in an optimal orientated classroom at a local primary school. Ceiling temperatures are also measured for a classroom at 7 Fountains and at the local school.

3.3 Results

The humidity data confirms the very dry climate in the Kokstad region; it shows no significant fluctuations or potential sources of discomfort in summer. The dry winter may require some sort of humidification however this has not been investigated further.

The indoor air temperature of an optimally orientated classroom at 7 Fountains during a week in April, is maintained at a comfortable 20°C which is approximately 10-15°C warmer than the outdoor temperature (figure 5). A non-North facing classroom is about 5-10°C warmer than the outside temperature whereas a North facing classroom in a building that has not been built with passive design principals (the classrooms are over-shaded by deep walk ways on the North) is only 3-5°C warmer than the outdoor temperature. All the classrooms function to reduce the extreme variance in outdoor temperature, with the optimal orientated classroom performing best. The warming effect of children in the class can be seen in the mornings when the indoor air temperature increases faster than the outdoor temperature.

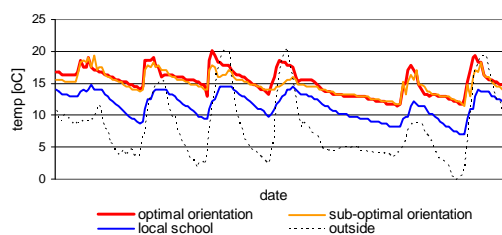


Fig 5. Comparison of temperatures in classrooms with optimal/sub-optimal orientation and a local school: Wed 4 – Tues 10 June 2008

The effect of insulating the ceiling results in ceiling temperatures closely matching the ambient indoor air temperatures and removes a potential source of discomfort of having a surface radiating heat or cold to the occupants. Figure 6 shows a classroom that is well insulated – the ceiling temperature follows the air temperature closely; whereas Figure 7 shows a classroom with no ceiling insulation – the ceiling temperatures are more extreme than the air temperatures. The outside air temperature is also

shown on the graphs as an overall indication of the thermal performance.

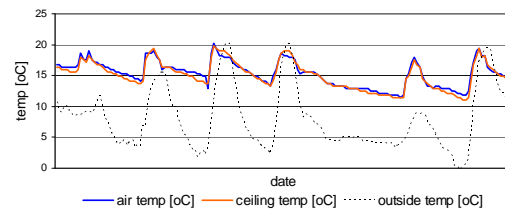


Fig 6. Air, ceiling and outside temperature for a classroom at 7 Fountains: Wed 4 – Tues 10 June 2008

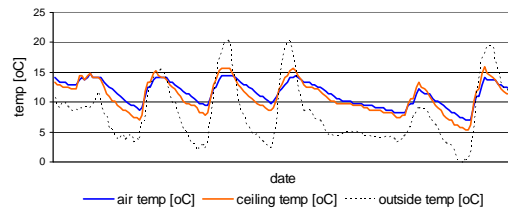


Fig 7. Air, ceiling and outside temperature for a classroom at local school: Wed 4 – Tues 10 June 2008

4. Thermal performance of classroom walls

Insulating walls is common practice in many cooler countries however in most parts of South Africa this is seen as unnecessary. Given the extreme temperature variation in Kokstad, the addition of wall insulation can significantly improve the thermal performance of a brick cavity wall.

In rural South Africa, traditional building methods use mud-bricks in a circular 'rondavel' floor-plan. One of the classrooms at the school is built in this format with help from members of the community. While mud-brick construction may be seen as a less modern way of building, the thermal performance of straw reinforced mud-bricks has superior insulating capabilities to concrete brick construction [5].

4.1 Design strategies

The thermal performance of the conventional brick wall envelope is greatly increased by the addition of insulation in the cavity (0.6W/m²K). A multi-cultural teaching room was constructed using traditional hand-made mud bricks containing straw to improve the strength and insulating capacity of the material. The intention was to demonstrate that traditional construction methods are appropriate to the climate and can have similar performance to modern methods.

4.2 Measurements

This experiment set out to compare the thermal performance of the insulated cavity wall and the mud brick wall. Temperature sensors were placed in the wall at four different intervals (on the inside wall surface, inside of the insulation, external to the insulation and on the outside wall surface as in figure 8). A set of data was collected for both the brick cavity with insulation wall and the traditional mud-brick wall.

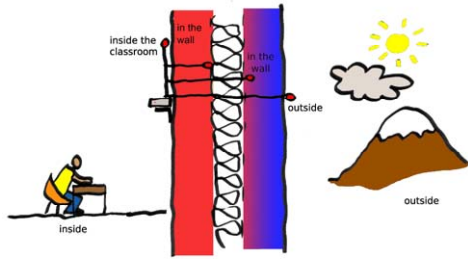


Fig 8. Graphic showing position of temperature sensors through the cavity wall

4.3 Results

During cold months (figure 9) the insulated cavity brick wall performs very well with indoor surface temperatures 5-10°C warmer than the outside surface temperatures. The mud-brick (figure 10) wall performs well with indoor wall temperatures that remain consistently 5°C warmer than the cold outdoor wall temperatures (figure 10). The average indoor surface temperature of the mud-brick wall is approximately 5°C cooler than the insulated cavity brick wall, however this may also be a result of the larger volume and less frequent use (lower internal gains) of the mud-brick room.

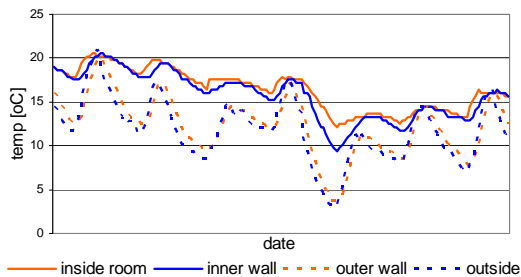


Fig 9. Temperature profile through wall of brick with insulated cavity: Tues 24 - Mon 30 July 2007

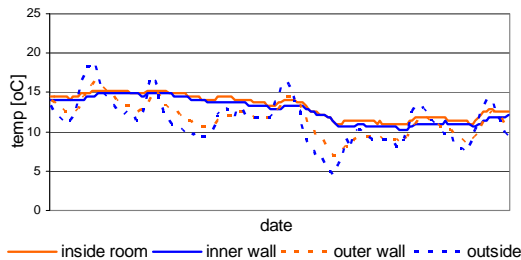


Fig 10. Temperature profile through wall of mud-brick: Tues 24 - Mon 30 July 2007

In the warmer summer months, the insulated cavity brick classroom never overheats remaining between 20-25°C (figure 11) despite high outdoor temperatures. The mud-brick classroom (figure 12) performs similarly on warm days and maintains a very even temperature between 20-23°C.

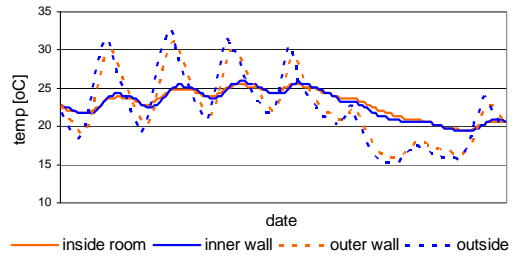


Fig 11. Temperature profile through wall of brick with insulated cavity: Sun 30 Dec-Sat 5 Jan 2008

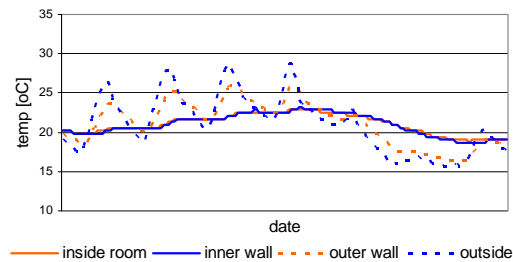


Fig 12. Temperature profile through wall of mud-brick: Sun 30 Dec-Sat 5 Jan 2008

5. Electrical energy consumption

Many rural schools in South Africa have no access to electricity and rely purely on daylight for illumination and chalk boards and books for educational tools. With the new construction, 7 Fountains Primary School were not only provided with electricity for electrical lights but computers, a television and other teaching aids were donated demanding additional energy and placing a cost burden on the school.

5.1 Measurements

The aim is to monitor electricity consumption and to quantify the additional electricity consumption burden that providing computers, a library and borehole pump will place on a low-income school such as 7 Fountains. While the donated teaching aids are very welcome at the school [6], it is important to identify the additional running cost. A system of three electricity meters were installed to measure the following consumption:

- the total incoming electricity
- block C which contains the computer room, library etc
- the borehole pump

5.2 Results

The electricity consumption follows the school calendar fairly closely with weekends and holidays shown as low consumption periods. There is little difference between winter and summer consumption due to the lack of electrical heating and cooling systems. Figure 13 shows an example summer week.

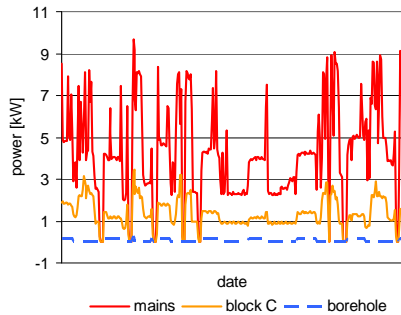


Fig 13. Power drawn: example week Wed 16-Tues 22 January 2008

Table 1 shows monthly electrical consumption for four given months. The difference in consumption during the holidays compared with term time is evident as is the percentage additional electricity consumption due to facilities in block C and the borehole pump. On average these extra electrical devices demand an additional 39% electricity above the standard school buildings. It is interesting to note that during the December holidays, the borehole pump was used as much as during term time. This could either be from tanks continually topped up with borehole water that overflows to the reservoir or it could indicate that members of the community are using the school's water system during the holidays.

Table 1. Selected months' electrical consumption for the three meters and percentage additional consumption due to block C and the borehole pump

month	school activity	mains [kwh]	block C [kwh]	borehole [kwh]	% additional consumption
Nov 2007	term	3866.7	1517.7	62.4	40.86
Dec 2007	holidays	1460.2	573.4	56.3	43.12
Jan 2008	half holidays	2664.1	836.1	46.7	33.14
May 2008	term	3095.7	1118.2	52.9	37.83

6. Water consumption

The township of Shayamoya is connected to the Kokstad municipal water system however supply is limited to two hours in the morning and two hours in the evening with little water pressure and flow available.

6.1 Design strategies

The toilets are connected to a non-potable water system (utilising the pipe distribution to the fire hose reels) that is fed by surface runoff collected in a large reservoir for seasonal storage and pumped to header tanks (daily storage) using a wind pump. The wash hand basins, drinking fountains and solar water heaters are fed from header tanks connected to mains water and the borehole. Overflow from the 40m³ header tanks flows back to the reservoir. Roof runoff is collected in separate storage tanks (with overflow to surface drainage to the reservoir) and used for garden irrigation.

6.2 Measurements

Loggers are installed at three water meters to measure the water consumption of the following:

- toilets of a junior ablation block

- wash hand basins of a junior ablation block
- solar water heater system

6.3 Results

The usage pattern of ablation water shows clear spikes during school time particularly during the 10am and noon break times. Almost no water is used over the weekends (figure 14).

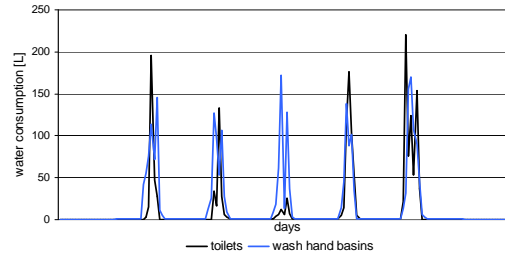


Fig 14. Water consumption for an ablation facility: example week Sun 7 – Sat 13 October 2007

The pattern of hot water consumption is more even throughout the day with some water use over the weekends. This suggests that cleaning staff or members of the community use hot water over the weekend (figure 15).

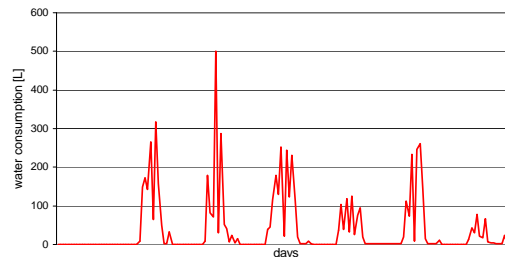


Fig 15. Hot water consumption at solar water heaters: example week Sun 7- Sat 13 October 2007

The actual monthly water consumption shown in figure 16 illustrates general trends of water use including the distinct difference between term time (October) and holidays (December). Malfunctions in the system can also be picked up from the data - in November there is evidence of a problem with the wash hand basins as the consumption is significantly higher than on an average month. One surprising result evident from the data is that aside from possible mechanical malfunctions, on an average day, the wash hand basins in this ablation facility use 10% more water than the toilets. This suggests user error such as leaving taps running or failing to flush the toilets after each use. It is likely that most of the learners do not have flush toilets or indoor running water at home and therefore may not understand correct usage practices.

While the graph shows hot water consumption higher than for toilets and wash hand basins, the solar water heaters supply hot water to the entire school whereas the bathroom that is monitored is only one out of four facilities for learners. There are also additional teachers' facilities. If this data is extrapolated to estimate total consumption, we can estimate that toilets, wash hand basins and the solar water heaters use almost 6m³ per day during the school term. Of that, 5 m³ is for bathrooms.

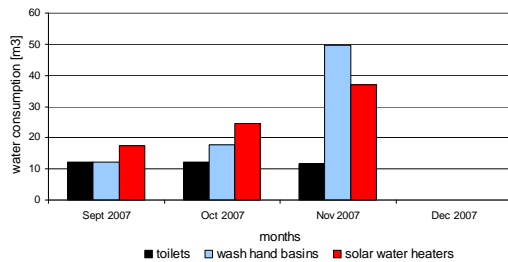


Fig 16. Metered monthly water consumption

On an average month 45% of the water used in the bathrooms is for toilet flushing and comes from a non-potable source. This represents a significant saving of potable water.

It would be interesting to perform these measurements in another toilet facility to determine whether the trends are similar with the older learners.

7. Conclusions

The monitoring of the performance of passive and sustainable strategies at 7 Fountains Primary School has shown that simple cost-effective strategies can have a marked outcome on the comfort and resulting performance of learners and educators. In summer, classrooms do not over-heat and winter temperatures are on average 10°C warmer than outdoor temperature. Daylight levels are significantly higher with minimal use of electric lights. When they are used, the lights on the darker side of the class are turned on first. This was aided by the installation of informative posters suggesting that such tools should be installed in all classrooms at occupation which could further influence the performance related to opening and closing of windows at different times related to season.

Insulated cavity walls in winter provide an indoor surface temperature of 10°C higher than outdoor surface temperature. In summer, indoor wall temperatures remain between 20-25°C despite high external temperatures. Results indicate that a regularly occupied mud-brick construction classroom could perform similarly, supporting the applicability of traditional construction methods to the local climate.

The addition of electricity-demanding facilities such as computer rooms, libraries and borehole pumps require an additional 39% electricity that the school administration has to pay for. An innovative water system provides continuous supply for toilets, wash basins, drinking fountains, and warm water for cleaning and cooking. 45% of the water used in toilet blocks is non-potable which represents a significant saving in potable water from municipal mains and the borehole. However further user education could reduce the wash hand basin use as it appears to be excessive. An impact similar to that on the electrical lights usage may be seen through user education.

Throughout the project, a strong emphasis was placed on the involvement of the staff at the school. While there have been some obstacles in

this process such as missing data, malfunction of logging systems and files not able to be sent, the benefits have been invaluable. There is a feeling of ownership towards the performance of the school as well as the data that demonstrates this.

7.1. Future steps

The project is ongoing monitoring and the aim is for the educators of 7 Fountains to take over the entire process of downloading and manipulating data. This is valuable for academic purposes, educational tools in the classroom and to identify operation and maintenance issues (overuse of wash basin water and water leaks).

An additional monitor has been placed in a classroom at an exclusive private school in the area. Future data assessments will provide a comparison between an up-market school building and the 7 Fountains classrooms.

The data gathered in this exercise is already being used to influence design decisions in other rural schools. It is our hope that Department of Education will begin to incorporate passive design strategies in their school building guidelines.

8. Acknowledgements

The South African National Energy Research Institute (SANERI) and the international donor for funding the monitoring equipment. The staff at 7 Fountains Primary School provided invaluable help in installing the loggers and downloading the individual data sets. East Coast Architects for leading the design team and creating opportunities and a positive design environment to include these strategies. Builder and design team for being open to new ideas.

9. References

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