Retrofitting Old Silk Factory in Valmadrera, Italy with Insulated Envelope Solutions.

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Abstract. Building industry is responsible for almost 50% of the world’s total energy demand. It takes more energy to operate buildings than it takes to run the manufacturing or transportation industry. In the drive for climate change, a lot of work is being done by policy makers for making new projects better aligned with environmental and energy conservation goals. It is not enough to only focus on improving the climate response of new construction. Work also needs to be done on improving the energy performance of existing building projects which will in turn further reduce the CO₂ footprint of the building operations industry. One way to reduce the energy consumption of existing buildings, is to add insulation to façade elements during building retrofitting projects. The purpose of this research is to shed light on probable options and benefits for adding insulation to traditional envelopes. This will enhance the operating capacity of buildings without the need for demolition or re-construction. This project demonstrates the energy efficient retrofitting of an old silk factory in the historic city of Valmadrera, Italy to act as a prototype project testing suitable options for adding insulation to existing structural systems. One of the biggest challenges for this type of upgrade is the porous nature of the existing building material and how it conflicts with the hygroscopy of synthetic insulation materials. The research suggests the use of organic insulating materials for the envelope elements. At the same time it also offers valuable suggestions for future explorations. This research has a high impact value globally, due to the vast treasure of historical architecture buildings which need to be preserved, but also need improvement in terms of their technological performance. Furthermore, it holds strong relevance for the Saudi Vision 2030 because preserving local architectural practices, materials and techniques is a significant part of the national motivation to preserve Saudi cultural identity.

Key Words: Retrofitting, Insulated Envelope Design, Sustainability, Energy Efficient Design, Traditional Buildings, Saudi Vision 2030.
1. Introduction
The research is about an old silk factory located in the small town of Valmadrera in Italy which was converted into a “Youth Centre”. It was a group project carried out by 3 members and we thank everyone for the contribution they made to the project. The project encompassed two main parts. One dealt with preservation, repair and thermal improvement of the factory with the aim of retaining the original materials and character as much as possible while bringing it up to the current building codes and standards. The second part of the project was a new construction inside the spinning mill of the former silk factory. This was a relatively newer part of the structure and worn down so the decision was made to demolish it and re-construct an event venue over it which could be rented out. Being a new construction, the envelope design for the “Event Venue” is not under discussion and the focus would be on the retrofitting of the original building.

The Silk factory was constructed with massive walls, giving it good thermal mass but no insulation was provided to any of the façade elements. Additionally, the structure of the factory was not air-tight resulting from wear and tear over the life of the building and the lack of resources at the time of construction. The joints between different wall and flooring members were not tight resulting in significant infiltrations which was causing large energy and air-conditioning losses throughout the year. Thus, before the building could be fitted with the latest air-conditioning and heating systems and made energy efficient, the envelope elements of the building needed to be strengthened and improved.

2. Literature Review
Various projects and case-studies were reviewed to get an idea about how to approach the energy efficient retrofitting of an existing building. One such case study referred to was a building in China, Tinajin [1]. Through this research we came to know different ways of accessing the effectiveness of proposed retrofitting solutions in terms of their energy efficiency. Another research carried out by Huang, Hu, Niu, J and Chung, T in 2013 presented interesting insights into different factors to consider for a hotter climate. Due to the challenge of finding suitable materials to be used an insulation, we wanted to study the evolution of insulating materials and how they have changed. The research done by Bozsaky, David (2010) offered a great insight into the development of insulation materials over the years. Furthermore for an existing building, adding the insulation material on the inside holds a multitude of benefits as compared to adding it on the outside and a comparative study helped us a lot in making this decision like the one conducted by Kolaitis, D, Malliotakis,E, Kontogeorgos, A, Mandilaras, I, Katsourinis, D and Founti,D. in 2013. Lastly, hygrothermal properties of the lime-stone walls and high porosity becomes a major factor. This is important in any energy efficient retrofitting while involving building materials with porous characteristics. [5]
3. Methodology

**Literature Review** - Carried out to understand the current research available and find opportunities to add on to it

**Case-Study Analysis** - Study similar projects to understand key issues to focus on during the research

**Project Modeling on Software** - A detailed 3d model of the project, developed on Design Builder

**Energy Analysis** - Different climatic conditions tested for various envelope material solutions to simulate an indicative energy performance of the building using energy plus

**Recommendation, Results and Conclusion** - Graphical comparison of final results with recommendations

4. Findings and Actual Research Presentation

4.1 Envelop Insulation Design – Background

One of the biggest challenges while finding appropriate insulation for this building was the porous nature of the existing structural materials. It was an old construction made up of massive walls in lime bricks and stones. Even though the walls inherently had a high thermal mass but no insulation had been provided. In order to re-use, it needed to be retrofitted in order to bring it up to the minimum insulation standards as prescribed by the codes. Since the building walls, floor and roof were made of highly porous materials it was not possible to choose a standard synthetic insulation material for the walls. All synthetic insulation materials are highly sensitive to moisture exposure and need to be protected against the ingress of water vapour. Since the existing façade is like a breathing membrane, it is very difficult to ensure that no water vapour will come in contact with the insulating layer. Such a solution in an old building was not possible because at any given time about 60-50% moisture is entrapped in the floors and walls of the building and if it is not allowed to escape it can cause serious condensation problems resulting in the formation of microorganisms and rendering the insulation materials ineffective. Thus, alternative solutions were selected which will be discussed below.

4.2 Solutions for existing building elements

Breathing and porous insulation solutions were devised for all the existing building elements such as roofs, walls and floors. The details of each have been given below.
4.2.1 Existing Façade Walls – Insulation

The unique solution for insulating the external building structural walls has been provided with a table showing the final calculation for the wall element (Figure 1.) and the layers making up the wall member (Figure 2.). The target was to achieve a U-value anywhere around 0.25 to ensure satisfactory level of performance. One motivation was to preserve the external look of the building. Because of the historical character of the structure, there was a high inclination to maintain the natural stone brick façade. Thus an internal insulation fixation solution was suggested. The breathable nature of the façade coupled by thermal mass already offered a good time lag between the diffusion of heat in and out. The insulation material to improve the energy performance of the wall was chosen to keep the breathing performance and thermal mass properties of the original brick wall intact to enhance the original character. The insulation materials used was Wood Fibre Board. Gutex Woodfibre Board was chosen because of the following advantages;

- Low thermal conductivity
- High volumetric heat capacity
- Superb vapour permeable design

| Layer No. | Description of Material | λ (w/m.k) | S (m) | R (m².k/W) |
|-----------|-------------------------|-----------|-------|------------|
| 1         | Existing Brick Wall     | 0.3       | 0.52  | 1.733      |
| 2         | Lime Planter            | 0.66      | 0.002 | 0.005      |
| 3         | Wood Fibre Board Insulation | 0.04 | 0.1   | 2.500      |
| 4         | Lime Planter            | 0.66      | 0.002 | 0.003      |

\[ U = 1 \left( \frac{1}{S_1} + \sum \frac{S_i}{\lambda_i} \right) \]

\[ \sum S_i = 4.24 \quad \frac{1}{S_1} = 1.733 \quad R = 0.17 \quad \frac{1}{\lambda} = 0.04 \]

\[ U = 0.22 \]

Figure 1. Thermal conductivity of existing wall

Figure 2. Insulation detail of existing wall
4.2.2 Existing Roof – Insulation

The guidelines while choosing the insulation material for the roof were the same. The porous character of the roof demanded an innovative selection. In order to keep the breathing performance of the roof intact hemp lime insulation was chosen along with GUTEX wood fibre boards. Another problem was that the structural integrity of some of the roofing members was already compromised. The rafters were failing and cracking under the load and wear/tear of all the years was quite evident. In order to offer some support to the rafters, a combined approach of above and between rafters insulation was adopted. It can be seen in the figure below.

Below is the table which shows the calculations for the thermal performance of the altered roof element after the addition of the insulation material layers. The aim of this exercise was to improve the thermal insulation character of the roof but we wanted to attain a higher U-Value for the roof, as compared to the walls. This is because roof is a major source of heat gain and heat loss as it is completely exposed to the exterior climatic elements. A U-Value of 0.13 was achieved with the selected solution.

| ELEMENT       | ROOF |
|---------------|------|
| Layer No.     | Description of Material                                      | λ (W/mK) | R (m².K/W) | B (m³.K/W) |
| 1             | Hollow Clay roof Tiles with air flow permitted (1/2" thick)   | 0.026     | 0.0127     | 0.488      |
| 2             | Wooden Battens (20 cm deep)                                   | 0.18      | 0.2        | 1.111      |
| 3             | Counter Wooden Battens for ventilation                        | 0.18      | 0.1        | 0.556      |
| 4             | Vapour Permeable Membrane                                     | 0.3       | 0.002      | 0.007      |
| 5             | Wood Fibre Board Insulation (Sarking Insulation) above rafters| 0.04      | 0.06       | 1.500      |
| 6             | Hemp Lime Insulation between rafters                          | 0.08      | 0.32       | 4.000      |
| 7             | Lath and lime Plaster tiles (Retained)                        | 0.4       | 0.0127     | 0.032      |

\[ U = \frac{1}{1/\text{h} + \sum \frac{1}{\text{h}}} \]

\[ \sum \frac{1}{\text{h}} = 7.69 \quad 1/\text{h} \quad 0.17 \]

\[ U \text{ Value} = 0.13 \quad 1/\text{h} \quad 0.04 \]
4.2.3 Existing Floor – Insulation

Even though it was critical to maintain the breathing character of all the existing building material, this was exceptionally crucial for the flooring system of the Silk Factory. More than 50% of the moisture exchange that happens in the building is due to the floors and thus the flooring material is hugely responsible for giving the building its porous element. Lime was also the structural material for the existing floors and all retrofitting solutions that were done, were developed with this in mind. However an additional challenge was so find a retrofitting solution which could also incorporate in-floor piping system for the under-floor heating which was being suggested.

The existing composite lime concrete floor has been retrofitted to make it improve its insulation properties and integrate under floor heating system into the existing floors. The idea for the flooring system has been taken from the limecrete floor system developed by Ty’- Mawr Lime Ltd. The solution suggested construction of the floor system but it has been retrofitted with our current floor as follows;

- The existing lime concrete floor has been used as the main structural layer
- The insulating layer of light weight expanded clay aggregate on top of it
- And lastly hydraulic lime screed is put for leveling of the floor and integration of under floor heating pipes

![Figure 6. Insulation details existing floor](image)

![Figure 7. References for floor insulation (Ty*Mawr lime)](image)

![Figure 8. Thermal conductivity calculations](image)
5. Conclusion and final holistic performance achievements
As shown by the results of the thermal conductivity calculations above, the insulating character of the building envelope was improved significantly. This would result in a decrease in the overall space heating, cooling and ventilation requirements, thus reducing the need for a big HVAC system. The building still needs to be fitted with HVAC solutions, but the size of the system would be greatly reduced as a result of these interventions. This would in turn result in increased comfort at reduced building operational loads.

6. Recommendations for Further Research
This research is just a preliminary level start to the development of solutions for energy-efficient retrofitting of existing buildings. There are a multitude of challenges while choosing insulation materials for porous and breathable materials, of which most of the traditional buildings are made of. Even in Saudi Arabia, the traditional construction is stone and mud which does not work well with synthetic insulation materials. Efforts and resources should be invested in coming up with organic insulation materials which work well with breathable membrane structures.

7. References
[1] Zhou Z, Zhang S, Wang C, Zuo J, He Q and Rameezdeen, R 2016 J. Cle. Prod. 112 3605-3615
[2] Huang Hu, Niu J and Chung T 2013 Applied Energy 103 97-108
[3] Bozsaký D 2010 Per. Poly. Arch. 41 49-56
[4] Kolaitis, D, Malliotakis,E, Kontogeorgos, A, Mandilaras, I, Katsourinis, D and Founti,D. 2013 Energy and Buildings 64 121-131
[5] Koci V, Jerman M, Pavlik Z, Madera J, Zak J and Cerny R 2020 Energy and Buildings 222 110093
[6] Rauf K, Moldovan R, Dmitrasinovic O 2013 Politecnico di Milano

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