CHARMS

Energy-Efficient Retrofit of Wooden Heritage Buildings in Chiang Mai by Nature-Based Interior Insulation on the Basis of Typha

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The traditional wooden Thai house, which also can be found in Chiang Mai, represents local and sustainable climate adapted building tradition with an open construction designed for high natural air exchange rates to achieve a more convenient thermal comfort, maintain good air quality, and remove moisture. However, due to urbanization and climate change induced rising temperatures, tolerable indoor temperatures are no longer ensured to a sufficient extent by natural ventilation. Moreover, the unhealthy air pollution in Chiang Mai also affects the indoor air quality negatively. Thus, today many wooden houses are retrofitted with air conditioners, which lead to high energy consumption and contribute to the amplification of the urban heat island effect, or are even demolished. These circumstances have led to a sharp decline of traditional wooden houses in Chiang Mai and thus to the loss of cultural identity. Many houses have been replaced by concrete buildings, which also means a significant decline in terms of ecologic building design. Thus, it is important to preserve traditional wooden houses by retrofitting them with new sustainable, climate-friendly technologies and materials. This report presents possible solutions to address these challenges. Workshops were held at Chiang Mai University, where several solutions developed at Fraunhofer IBP were presented and discussed with local stakeholders. Especially the Typha board, an innovative construction and insulation material made of cattail (Typha), was considered as particularly interesting.

Typha as a raw material combines numerous structural, building-physical as well as ecological and economic advantages like low thermal-conductivity, mechanical strength, and biological resistance. Moreover, the plant is widespread throughout the world, can be established very fast and is characterized by an enormous productivity. It also can be used for the creation of ecologically valuable wetlands with important functions like a long-term bondage of CO_2, water retention, and purification of nutrient polluted surface water. In addition, the magnesite bonded Typha board is hardly flammable and completely compostable. Due to its insulating and stabilizing properties, it could be used as interior insulation and for reinforcement of load-bearing structures or stiffening of the buildings. Additionally, the Typha board could be used to seal the countless joints of


Photography by David Gardiner, from unsplash

the walls to substantially reduce the infiltration of polluted air. Furthermore, a reduced air exchange rate combined with thermal insulating properties of Typha increases the effectiveness of air conditioners and decreases the energy consumption of electricity significantly. The next step for the CHARMS-team will be to assess the transferability of the Typha board in wooden houses in Chiang Mai with the aim of retrofitting them in an energy-efficient and sustainable way.

For this purpose, it is planned to conduct comparative simulations and modeling and thus to investigate its performance regarding climatic boundary conditions in Thailand. At the same time, the options to produce Typha in the urban hinterland are assessed considering questions of energy efficiency, water retention and purification, and food security from a nexus perspective.

บทคัดย่อภาษาไทย
อาคารบ้านไม้โบราณที่พบได้จังหวัดเชียงใหม่แสดงถึงภูมิปัญญาและองค์ความรู้ท้องถิ่นของการสร้างบ้านเรือนที่ปรับให้เข้ากับภูมิอากาศท้องถิ่น ด้วยการออกแบบโครงสร้างของบ้านที่เปิดโล่งเพื่อให้อากาศสามารถถ่ายเทได้สูง ทำให้บ้านไม้โบราณมีความสบายในเชิงอุณหภูมิเพื่อการอยู่อาศัย มีคุณภาพอากาศที่ดี และสามารถกำจัดความชื้นภายในบ้านได้ อย่างไรก็ตามในปัจจุบันประเด็นของการขยายเมือง (Urbanization) และ การเปลี่ยนแปลงสภาพภูมิอากาศ (Climate Change) ส่งผลทำให้อุณหภูมิเพิ่มสูงขึ้น ระบบระบายอากาศตามธรรมชาติไม่สามารถตอบสนองความสบายในเชิงอุณหภูมิภายในอาคารได้ ยิ่งไปกว่านั้นปัญหามลพิษทางอากาศในจังหวัดเชียงใหม่ส่งผลกระทบเป็นอย่างมากกับคุณภาพอากาศภายในอาคาร ด้วยเหตุนี้ทำให้เจ้าของบ้านไม้โบราณเลือกที่จะปรับปรุงบ้านโดยการติดตั้งเครื่องปรับอากาศภายในบ้าน ซึ่งทำให้อัตราการใช้ไฟฟ้าในครัวเรือนสูงขึ้นและก่อให้เกิดเกาะความร้อนในเมือง (Urban heat island) ที่เพิ่มมากขึ้น รวมถึงการที่เจ้าของบ้านไม้โบราณเลือกที่จะรื้อถอนบ้านและแทนที่ด้วยการสร้างบ้านคอนกรีต ทำให้จำนวนบ้านไม้ในจังหวัดเชียงใหม่มีจำนวนลดลงอย่างรวดเร็ว นอกจากการรื้อถอนจะทำให้ท้องถิ่นสูญเสียความเป็นอัตลักษณ์แล้ว ยังส่งผลถึงการลดลงของอาคารที่ออกแบบอิงต่อนิเวศวิทยา (Ecologic Building Design) อีกด้วย ด้วยเหตุดังกล่าวทำให้คณะวิจัยเห็นถึงความสำคัญในการอนุรักษ์และปรับปรุงอาคารไม้โบราณด้วยเทคโนโลยีหรือวัสดุที่มีความยั่งยืนและเป็นมิตรต่อสิ่งแวดล้อม

รายงานฉบับนี้มีจุดประสงค์ในการนำเสนอนวัตกรรมต่างๆเพื่อแก้ไขปัญหาของบ้านไม้โบราณซึ่งคิดค้นและพัฒนาโดย Fraunhofer IBP ผ่านการอบรมเชิงปฏิบัติการ (Workshop) ที่จัดขึ้น ณ มหาวิทยาลัยเชียงใหม่ โดยการอบรมฯดังกล่าวได้มีการนำเสนอนวัตกรรมและหารือกับผู้มีส่วนได้ส่วนเสียในท้องถิ่น โดยเฉพาะประเด็นของการนำนวัตกรรมแผงธูปฤาษี (Typha board) มาใช้ในการก่อสร้างและฉนวนกันความร้อนภายในอาคารบ้านไม้โบราณ

ต้นธูปฤาษี (Typha) เป็นวัสดุจากธรรมชาติที่ปลูกกันอย่างแพร่หลายในทวีปต่างๆทั่วโลก ด้วยโครงสร้างที่ซับซ้อนของเส้นใย ลักษณะทางกายภาพ การนำความร้อนต่ำ มีความแข็งแรงเชิงกล มีความทนทานทางชีวภาพ สามารถเจริญเติบโตได้อย่างรวดเร็ว และมีผลผลิตสูง จึงเป็นข้อได้เปรียบทั้งในเชิงนิเวศวิทยาและเศรษฐกิจ นอกจากนี้บริเวณเพาะปลูกธูปฤาษียังสามารถเป็นบริเวณพื้นที่ชุ่มน้ำ (Wetland) ที่เป็นประโยชน์ในเชิงนิเวศวิทยาในการกักเก็บก๊าซคาร์บอนไดออกไซด์ (CO_2) สามารถพื้นที่กักเก็บน้ำ รวมถึงบำบัดแร่ธาตุบนผิวน้ำได้ด้วย ในกรรมวิธีผลิตแผงธูปฤาษีนั้นเส้นใยถูกประสานกันด้วยแมกนีเซียมซึ่งมีคุณสมบัติติดไฟยากและสามารถย่อยสลายได้ตามธรรมชาติ ทำให้แผงธูปฤาษีสามารถนำมาใช้เป็นฉนวนกันความร้อนภายในอาคารและเป็นวัสดุเสริมโครงสร้างรับน้ำหนักเพื่อเพิ่มความแข็งแรงของอาคารได้ รวมถึงใช้ในการปิดช่องไม้เพื่อลดปริมาณมลพิษอากาศที่เข้าภายในบ้าน นอกจากนี้ยังช่วยเพิ่มอัตราการถ่ายเทของอากาศภายในอาคารส่งผลให้การใช้พลังงานไฟฟ้าในบ้านที่มีประสิทธิภาพมากขึ้น

ขั้นตอนต่อไปในการดำเนินงานวิจัยคือการประเมินความเป็นไปได้ในการติดตั้งแผงธูปฤาษีภายในบ้านไม้ในจังหวัดเชียงใหม่ ด้วยวิธีการวิเคราะห์เชิงเปรียบเทียบ (Comparative Simulation) และ การสร้างแบบจำลอง (Modeling) ซึ่งเงื่อนไขของการทดลองดังกล่าวมีจุดประสงค์เพื่อวัดประสิทธิภาพการใช้งานของนวัตกรรมกับสภาพภูมิอากาศของจังหวัดเชียงใหม่ โดยมีเป้าหมายเพื่อให้บ้านไม้โบราณสามารถใช้พลังงานได้อย่างมีประสิทธิภาพและยั่งยืน ในขณะเดียวกันประเด็นของการเพาะปลูกธูปฤาษีในพื้นที่ชนบทจะถูกนำมาอภิปรายในแง่ของผลกระทบต่อการอนุรักษ์พลังงาน การกรองและกักเก็บน้ำ รวมถึงการเชื่อมโยงกับประเด็นของความมั่งคงทางอาหารอีกด้วย

Background and Problem Definition – Situation of Wooden Heritage Residential Buildings in Chiang Mai:

Thailand has a very rich cultural heritage. In architecture, the traditional wooden Thai house represents local and sustainable climate adapted building tradition which is more and more lost today. Traditional wooden residential buildings in Chiang Mai were usually built with wooden planks and boards fixed on a wooden frame or beams. Since the joints between the planks are not sealed there are smaller or bigger air gaps in the outer walls, which allow continuous ventilation in order to cool the interior, help to maintain good air quality and remove moisture from residential use in a natural and passive way. The leaking joints lead to higher air exchange rates and increased air velocity indoors and thus to a more convenient thermal comfort for inhabitants.

However, the cooling effect for indoor air temperature by high air exchange rates is limited to the level of the outdoor temperature. In the past this was one possibility to sustain a more or less acceptable indoor climate. Due to new and different comfort demand of residents in recent times, changing outdoor climate by the urbanization (urban heat island) on the one hand and rising temperatures as a result of climate change on the other hand, the traditional function of natural ventilation is no longer given to a sufficient extent in these traditional buildings. This circumstance not only causes an unsatisfactory thermal indoor comfort for the inhabitants, moreover, in many cases these buildings are retrofitted with air conditioners to cool the interiors. This leads to high energy consumption due to the high ventilation rate of the building and, on the other hand, contributes to the amplification of the urban heat island effect.

Finally, Chiang Mai City is notorious for its unhealthy level of air pollution, particularly during the dry season between January and May, the so-called haze season, when rice straw is burned in the surrounding countryside. In March 2019, Chiang Mai was ranked as the city with the worst air quality index (AQI) score worldwide (Wipatayotin, 2019). Due to the open wooden construction, the indoor comfort is thus also affected negatively by the entry of contaminated air leading to unhealthy air quality inside these buildings.

In the recent past, these circumstances have led to a sharp and in some places even to a very sharp decline in the proportion of traditional wooden houses in Chiang Mai City. The two pilot communities of the CHARMS project are good examples for this loss: Between 2019 and 2021, the Lam Chang community located in the historic city center lost 19 percent of its wooden, residential building stock in only two years. With a total loss of 34 percent, the loss in the second pilot community Wat Ket is even higher.

In many cases these houses have been replaced by modern apartment buildings made of concrete. This trend towards more concrete buildings leads to further negative consequences: Firstly, the loss of wooden building stock, whose existence and future use are of importance to many local residents, is accompanied by the loss of cultural identity. Secondly, the building material cement, which is required for the construction of concrete buildings, is characterized by extremely energy-intensive production and thus associated with very high CO2 emissions. The raw material wood, on the other hand, is considered a long-term carbon sink in the construction sector (Churkina et al., 2020), which means that the trend towards concrete can be evaluated as a completely wrong direction and significant decline in terms of sustainability and ecologic building design.

Thus, for reasons of building culture and sustainability, as well as for climate change impact adaption of the city of Chiang Mai, it is important to preserve the traditional houses made out of wood and retrofit them with sustainable and climate-friendly technologies and materials. This report presents possible solutions to address the aforementioned challenges related to the use of these traditional buildings.

Field Visits and Workshops in Chiang Mai in April 2022:

As a part of the CHARMS project, researchers of the Fraunhofer Institute for Building Physics IBP visited Chiang Mai in April 2022 to assess the site-specific boundary conditions from a building physics perspective. During the stay in Chiang Mai, the two pilot districts Lam Chang and Wat Ket were investigated. There, interviews were conducted with the inhabitants of traditional wooden houses in order to understand their experiences, problems

Figure 1: Wooden houses in the CHARMS pilot districts Lam Chang and Wat Ket in Chiang Mai.
Image sources: School of Public Policy, Chiang Mai University (SPP).

and needs resulting from living in this type of building. Two of the houses visited are depicted in figure 1.

The residents' reports on barriers and drivers of indoor comfort are consistent with previously conducted research and surveys. The main identified problems of the wooden houses from the point of view of building physics are:

- Lack of thermal indoor comfort, which for example was improved a little in one building via subsequently implemented natural ventilation in the form of a hole in the ceiling between the first and second floor (Fig. 2, photo 1), but is still far from comfortable.
- High energy consumption through the use of air conditioning, which is further increased by the fact that the wall constructions are not air tight (Fig. 2, photo 2), lack of sufficient heat insulation of wall components and have single-layer glazing (Fig. 2, photo 3). However, despite the high energy consumption of these systems and their contribution to the heat island effect, the workshops (and also unpublished existing results from a survey conducted in 2019) indicate that air conditioning systems are considered the most effective means for cooling indoor space.
- Unhealthy indoor air quality, which is caused by pollutants being transmitted from the outside air through the leakages in the wall structure (high air exchange rate).
- Additionally, lack of sound insulation and occasional damages in the building structures caused by insects (mainly by termites) (Fig. 2, photo 4) were also mentioned as further problems.

In addition to these field visits, workshops were also held at Chiang Mai University, to which representatives of construction companies, municipalities and academics were invited. These workshops aimed to present several solutions developed at Fraunhofer IBP and to discuss their applicability in Thailand with the local stakeholders. All of the presented materials and technologies aim at improving the energy, comfort and ecological performance of buildings. The discussions showed that especially the innovative construction and insulation material made of cattail (Typha) was met with very high interest. Therefore, the next sections focus on a short presentation of this product.

Typha as a Possible Solution to Improve Indoor Comfort:

As shown in projects funded by the DBU (Theuerkorn et al.), the use of Typha as a raw material for the production of building materials combines numerous structural, building-physical as well as ecological and economic advantages. The Typha leaves are particularly suitable because of their special properties of the plant, that include following benefits (Krus et al., 2021):

- Low thermal conductivity caused by the sponge-like tissue, which enables good insulating properties for the building material (Fig. 3, middle),
- Low specific weight due to this sponge fabric filling the leaf chambers,
- Mechanical strength of the product caused by a complex and stable fabric with high compressive and tensile strength of the leaves in the direction of their axes,
- High flexibility and elastic deformability perpendicular to the leaf axes allowing the addition of the inexpensive mineral binder magnesite.

Figure 2: Hole in the ceiling in order to facilitate natural ventilation (1st); Leaking construction (2nd); Installed air conditioning system and single layer glazing (3rd); Termite damage to the construction (4th) Image Sources: Fraunhofer Institute for Building Physics IBP (Fraunhofer IBP)

Furthermore, the Typha plant (Fig. 3, left) is characterized by a biological resistance to fungal and insect attack due to its natural equipment with tanning agents (polyphenols), which makes the application of chemical additives obsolete. With regard to the production of a building material, the raw material also has the advantage that it is easy and quick to process with common tools. Additionally, the cutting process is low energy-intensive, since Typha, unlike other renewable raw materials, does not contain SiO_2-components, which therefore makes it easily and permanently to cut with sharp knives.

To harvest the huge potential Typha offers to the development of sustainable building materials, the Fraunhofer IBP and the company typha technik Naturbaustoffe developed a load-bearing and insulating magnesite-bonded typha panel called Typha board (Fig. 3, right). In addition to the above-mentioned advantages specific to the raw material, the finished panel is hardly flammable (building material class B1, fire resistance class F60 to F120 depending on the thickness) and shows neither glowing and particular smoke development nor burn-dripping. Another benefit of the Typha board is its easy dismantling and complete compostability, which fully complies with the idea of minimizing negative environmental construction impacts through qualitative transformation coupled with the closure and deceleration of material cycles (cradle to cradle).

Moreover, the cultivation of Typha has several beneficial aspects. Firstly, the plant is widespread throughout the world and can be established very fast. Secondly, it is characterized by an enormous productivity of about 15 to 20 tons of dry matter per hectare and year, which can be used for approximately 150 to 250 m³ of building material. Thirdly, it thrives well in humid locations with medium to very high nutrient supply and a good

Figure 3: Typha plant; Leaf bundle cross-section; Load-bearing and insulating magnesite-bonded Typha board.
Image Source: Left – Petr Filippov, Wikimedia Commons; middle – Fraunhofer IBP; right – Fraunhofer IBP.

toleration of nutrient oversupply. On the one hand Typha cultivations can therefore be used for the creation of ecologically valuable wetlands with important functions like a long-term bondage of CO_2, which even exceeds the potential of wood cultivation by far, as well as water retention and additional habit for animals (Fig. 4). On the other hand a purification of nutrient polluted surface water is enabled by cattail cultivations.

A Nexus Perspective of the Cultivation of Typha in the Urban Hinterland of Chiang Mai City

Bio-based construction materials with a high technology readiness level such as the Typha board can contribute to the decarbonization of the construction sector and cater to the rapid urbanization of secondary cities in Southeast Asia. Given that radical emission cuts of urban environments are urgently needed, realistic solutions such as the Typha board allow both the adaptation to environmental changes that house-owners face already while mitigating operational and embodied emissions of urban living. At the same time, the relatively high technological maturity of the solution allows its adoption and diffusion in the Asian construction market within a short time frame.

To validate and realize the potential of the Typha board to improve the indoor comfort in wooden, residential buildings in the context of Thailand, the CHARMS-team approaches the next steps in the development and diffusion of Typha-based construction materials from a nexus perspective. Some of the guiding questions are:

1. Energy: Is it possible that a Typha board produced in the urban hinterland improves the indoor comfort while reducing the operational and embodied emissions of urban living in wooden, residential buildings in Chiang Mai City?
2. Water: In which way can Typha be produced that the co-benefits of Typha to create ecologically valuable wetlands, water retention and purification of nutrient polluted surface water are optimized?
3. Food Security: What are the consequences of the promotion of Typha cultivation in the urban hinterland of Chiang Mai City in terms of availability and access of sufficient quantities of food in an appropriate quality?

Thailand's agricultural sector is the second largest emitter of greenhouse gas emissions. About 60 percent of these emissions come from rice production (International Rice Research Institute [IRRI]). At the same time, rice farming is of high economic relevance in the urban hinterland of Chiang Mai. For these reasons, the supply-side activities related to the Typha board will focus on barriers and drivers for a sustainable, coupled production of Typha and rice in the hinterland of Chiang Mai City.

To prepare the ground for a potential market take-up, the CHARMS-team seeks feedback on the Typha board from the Thai construction industry. A first pitch of the Typha board to representatives of Southeast Asia's largest and oldest cement and building material company took place in July 2022 and it is currently planned to extend the engagement with other private sector actors in the next months.

Conclusion and Next Steps:

For the reasons mentioned above and also based on the results of the interviews and workshops, the raw material Typha itself as well as the Typha board as a sustainable construction and insulation material holds an enormous theoretical potential for application in Thailand. Due to its insulating and stabilizing properties, it could be used not only as interior insulation of the traditional wooden houses, but also for reinforcement of load-bearing structures. Renewable materials in general also offer the possibility for long-term storing CO_2 in buildings. In addition, the insulation of the interior walls also significantly increases the effectiveness of already existing air conditioning systems, which leads to a saving of the required energy. Furthermore, by applying the Typha board, a sealing of the walls could be achieved, resulting in a substantial reduction of pollutants entering from the outside.

Therefore, the next step will be to assess the transferability of the Typha board in wooden houses in Chiang Mai with the aim of retrofitting them in an energy-efficient and sustainable way. For this purpose, it is planned to conduct comparative simulations and modeling of traditional wooden houses and thus to investigate the performance of the building material with regard to climatic boundary conditions in Thailand. At the same time, the options or the production of Typha in the urban hinterland are assessed. As soon as the theoretical feasibility and the analysis of the potential for energy saving has been proven in this way, it is also intended to define a real laboratory in the pilot districts of Chiang Mai, in which the Typha board will be used in a real environment in order to survey the behavior of the building materials, energy consumption and its influence on the indoor comfort conditions.

Figure 4: Typha cultivation. Image Source: Technische Universität München (TUM)