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Green buildings: defining sustainable construction materials in Thailand

Pimsiri Thovichit
Iowa State University

Green buildings: Defining sustainable construction materials in Thailand

by

Pimsiri Thovichit

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David A. Block, Major Professor
Bruce L. Bassler
Christopher J. Martin

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For my family and Lim

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Abstract

Sustainability is an important concept in today's architecture and will be even more so in the future. Thus, selecting sustainable materials is one of the most important steps toward sustainable or green building. In Thailand, the study of sustainable architecture is just beginning, and is not well studied. In fact, sustainable design is usually misunderstood to be the same as energy conservation design. In this study, common Thai construction materials from two regions (Northern and Central) were examined and analyzed with regard to sustainability. The following features of sustainability were studied: embodied energy, environmental effects, harm to users, durability, availability, and recyclability. Concrete and other cement products were rated as brown materials (unsustainable) compared to other materials which were green (sustainable). For a green building to be built, however, not only the use of green or sustainable materials is important, but the appropriate techniques and system for reasonable applications should also be taken in to account. This study proposed three types of green buildings that consider the above-mentioned factors.

Chapter 1

Introduction

The world we live in today is full of pollution and junk. Many of our natural resources are used in construction materials and in the overall construction of buildings. Both the construction process and the finished product cause our environment both direct and indirect problems affecting the quality of life. The World Watch Institute found that in the United States, buildings use about 17 percent of the total fresh water flows, 40 percent of the total energy flow, and 25 percent of harvested wood. They are also responsible for 50 percent of Chlorofluorocarbons or green house gas. Moreover, they generate 33 percent of CO_2 emissions and 40 percent of construction waste materials.

As a result of these consumption numbers, it becomes clear that managing our use of natural resources is very important in order to maintain our present quality of life and protect our future environment. In Thailand, this concept is the focus of the Ninth National Economic and Social Development Plan (2002-2006), issued by the National Economic and Social Development Board (NESDB). The plan adopts the philosophy of a sufficient economy bestowed by His Majesty the King to his subjects as the guiding principle of national development and management. The philosophy of a sufficient economy is based on adherence to the middle path, a Buddhist principle about moderation. It is advocated to (a) overcome the current economic crisis that was brought about by unexpected change under conditions of rapid globalization, and (b) achieve sustainable development.

Sustainability includes doing good things for the environment and communities which results in energy conservation and economic investment. Architects can incorporate this principle into their work by creating sustainable designs. The American Institute of Architects (AIA) gives the following definition of sustainability: “The ability of society to continue functioning into the future without being forced into decline through exhaustion or overloading of the key resources on which the sustainability of the construction material system depends”. It clearly shows that the foremost step of sustainable design is the identification of construction materials and their components. Besides selecting material properties to fit the client's basic criteria, one should consider many other factors in order to create sustainable design. Among those factors is the life-cycle of the material and its ability to be recycled, the amount of energy saved in each process, the cost, waste management, and environmental impact.

There are plenty of materials available in contemporary Thailand. Most research conducted in Thailand concerns energy conservation issues. Some studies of proper materials for residents in Thailand are published by the Department of Alternative Energy Development and Efficiency (DEDE), the Thai Ministry of Energy. They suggest and encourage residents to use certain materials for buildings, but with a narrow focus on energy conservation. Though these do offer some help, these studies cover only one part of sustainable design. Designing for energy conservation only is not enough to sustain our societies and environment. To meet the highest potential of sustainability, these materials should be produced in a way that will reduce pollution, increase the overall quality of materials, and reduce expenditure.

This research provides a discussion about sustainable construction materials in Thailand. Several commonly used materials such as concrete, masonry, gypsum board, steel, glass, and tiles are evaluated for their sustainability. The research is presented in two major parts: material review and recommendations. The material review demonstrates the use of criteria to select an appropriate and sustainable material for a specific job. The basic criteria revolves around strength, cost, appearance, and suitability. Next, life-cycle, environmental impact, toxicity, and waste management are discussed to define sustainable materials. Following this is the recommendation section, which is a vital segment explaining the proper context for which each material is used in order to meet the sustainability goal. The recommendation is based on three major types of buildings: (1) traditional homes that use natural or passive cooling to make the house comfortable, (2) a building with an active cooling system that mainly uses an air conditioner to keep the building comfortable, and (3) a building that use both systems at different times of the day.

Chapter 2

Background of the area: Thailand

Thailand is located in Southeast Asia between latitude 5.5 and 20.5 North and longitude 97 and 105.5 East. It is bounded on the Northwest by Myanmar, on the Northeast by Laos, with Cambodia on the East, and Malaysia on the South. Thailand has an approximate area of 513,000 km^2. The country is divided into four regions according to geography and climate: North, Middle, Northeastern, and South.

Thailand's climate is generally hot because it is located along the Tropic of Cancer (23- 27' North) where the sun is at an extreme angle of 90° with the Earth. The country's humid climate is caused by the seas and oceans which engulf the Southern part of Thailand. There are two major wind directions passing through Thailand which cause the change of seasons: the Northeast wind and the Southwest wind. The Northeast wind carries the cool weather from China during winter while the Southwest wind carries moisture from the Indian Ocean, which then causes the rainy season in Thailand.

The North region of Thailand is elevated with many mountains and forests. Its climate is moderately cold (10-25 °c) during winter because of the Northeast wind. The low relative humidity (69.4%) compared with the other regions creates comfortable weather most of the year. Since there are many forests in the Northern region, insects such as bugs and mosquitoes are very common especially during summer.

The Middle region of Thailand is mainly lowland where many rivers pass, merge together, and flow to the sea. This region is covered with rich soil which is good for agriculture, but it always has floods in the rainy reason. The climate is very hot and humid. The temperature range is between 25-38 °c and the relative humidity is around 70-74%.

The Northeast region, known as Isan, is a hot (28-40 °c) and dry area. It is as hot as the middle region, but always feels hotter because of strong sun rays and the sandy soil which can hardly grow any vegetables. In South Isan, the shortage of rain and few rivers or forests to hold the water make the land a drier area.

The South region of Thailand is the peninsular area between the Indian Ocean and the Gulf of Thailand. This area is similar to the other tropical areas with evergreen forests, rubber plantations, coconuts, palms, and the coast. There are only two seasons – summer and rainy, unlike the rest of Thailand with three seasons. The climate of the South region is very much influenced by the sea. The precipitation is very high, and the rainy season, which is also called the monsoon, usually brings typhoons.

Figure 1: Map of Thailand

Climate and terrain are the major factors that dictate the differences in the characteristics of the buildings in each region. Traditional buildings were constructed to blend with nature and take into account traditional knowledge, and these building have been found in all four regions. This concept helps construct buildings that prevent uncomfortable conditions brought about by external factors like excessive wind and sun, as well as use the natural sources of energy to increase comfort in the building. In addition to this, using locally available materials in the construction is also economical and sustainable.

This research is focusing on recommending sustainable construction materials that are well suited to buildings in two regions: North (with its cool climate) and Middle (the center of industry and manufacturing). These regions are the large areas that have similar climates and abundant natural resources. How people manage the resources required for construction is very necessary; and sometimes living near abundant natural resources may cause people to disregard conservation or restoration.

Table 1: Summary of the geography, climate, and natural resource of Thailand

Regions		North	Northeastern	Middle	South
Geographic	terrain	High land, high mountain	Both high land and low land	Low land	Mountain and beach
	forest	Evergreen forest, pine forest, and mixed deciduous forest	70-80% dry mixed forest and deciduous forest	Mixed deciduous forest	Tropical evergreen forest Littoral or Mangrove forest
	river	Four major rivers	Two major rivers	Many major rivers and canals	Two major rivers
	soil	Hard and sticky	Crumble and sand	Crumble with mineral	Sand along the beach
	agriculture	Flowers and fruits	Livestock and annual crops	Rice and fruits	Coconut, palm, and rubber
Climate	general	Moderately comfortable	Like a desert, regularly hot and dry	Hot and slightly humid	Hot and humid
	winter	Very cold in the mountain areas	Very cold in winter and at night	Comfortable	No winter
	summer	Hot in summer	Very hot in summer	Very hot and humid	Very hot and humid
	rainy season	Regular rain	Seldom rain	Abundant rain	Typhoons and monsoons
Natural resources (for building materials)		High quality white clay Gypsum Limestone River sand (concrete mixture) Wood	Good quality clay Gypsum Limestone	Gypsum Limestone River sand (concrete mixture) Iron	Silica sand Rubber Coal, natural gas Wood Tin

Architecture and construction

Traditional architecture

The Thai traditional house has unique characteristics according to the geography, climate, belief, and people's lifestyles. Each region differs in its beliefs and culture which is reflected in the distinguishable detail. The traditional architecture is essentially the same in terms of materials, structure, and construction. Tradition dictates that the house is oriented along the east-west axis. It has two separate main sections. A private space which is walled in and functions as the bedroom, and the public space which is usually an open space that can also function as the living room, dining room and activity area. The kitchen and the toilet are usually located separate from the main building. There is very minimal furniture and people sleep on the wood floor. In addition, the different levels of the floor function as seating and living areas. The roof is normally steep to improve rain drainage.

The buildings are raised from the ground by the column and beam structure often made with wood. The column and beam structure creates the different levels which divide the space without using walls and encourages good ventilation. For common people, bamboo is normally used for siding and leaves for roofing. Wood columns and beams are also the materials used for rich people's houses with wood siding, wood-board floor, and tiles for roofing.

This study focused on two regions: North and Central. Northern traditional houses are always built around the center yard that could also be used for multiple functions and activities. The walls of the house are angled upward according to the tradition that the house should be built like the shape of a buffalo. Buffalos are very important in agriculture and are the symbol of health and plenty. Since the general terrain of the area is hilly, the beams and columns used in the structure are adapted to it. The long overhanging roof is a good wind shield during the winter and sun protector during summer.

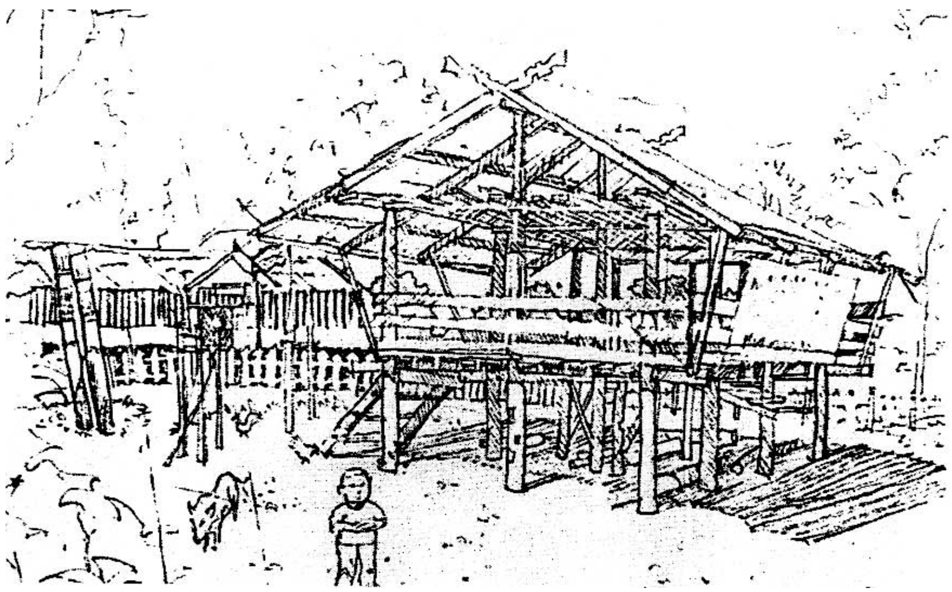

Figure 2: Traditional house in the Northern region

The Central region has a different building style. Because the middle region is mostly flat lowland, the column and beam structure allows the building to be elevated from the ground to keep the house safe during habitual floods during the rainy season. In accordance with the floating concept, the Central region traditional house always has a large veranda in the center of the separate buildings.

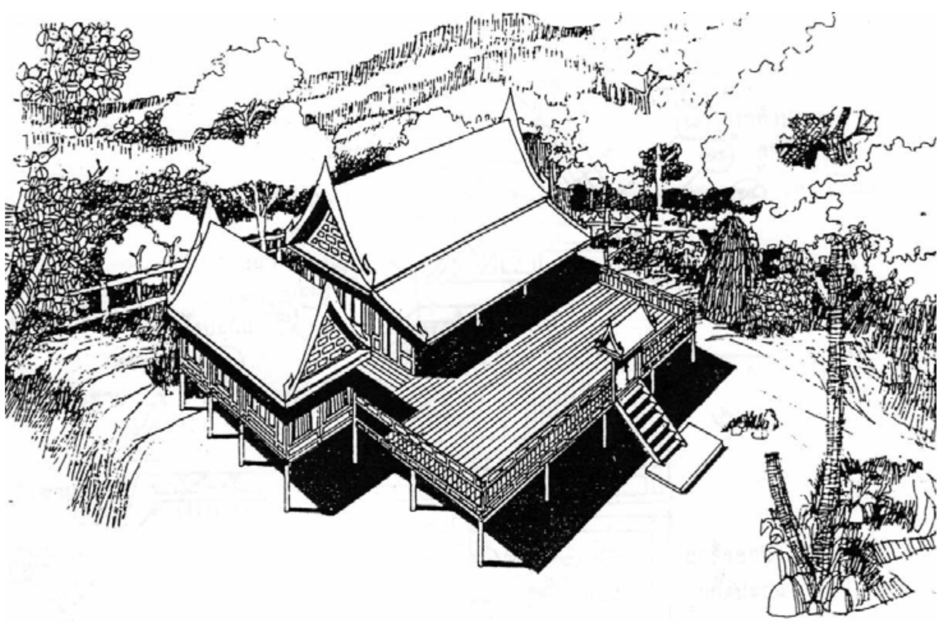

Figure 3: Traditional house in the Central region

Modern architecture

Thailand's present-day architecture is influenced by the Western style which is very different from the traditional buildings of the past. The house is one or two-stories, and is built on the ground instead of floating. Brick and plaster walls are very typical with a reinforced concrete column and beam structure commonly used for increased durability. Concrete tile, an inexpensive, mass produced roof tile, is common and flat roofing has become quite popular. Glass windows are in widespread use and can be found in most houses. Driveways are made of concrete and fences mostly of concrete block. This is a typical house that can be found all over the country and is constructed without concern for orientation, geography, wind direction, or beliefs anymore. The convenient appliances, contemporary furniture, and good sanitation have become requirements for comfortable living. Air-conditioning has become a very common factor to consider in most housing construction.

Figure 4: Thai modern architecture: construction with column and beam concrete and brick masonry wall

Figure 5: Thai modern architecture : High-rise buildings which are always built using concrete construction

Figure 6: Thai modern architecture – Subdivision houses.

Fences are common in Thailand.

Figure 7: Thai modern architecture – Commercial building

Figure 8: Contemporary Thai Northern style house where wood is still preferred. The structure is half concrete and half wood.

Chapter 3

Materials Review

Instead of wood, many other kinds of alternative materials such as concrete, brick, steel, tiles, glass, gypsum board, etc are sold in the market and widely used for modern architecture and construction in Thailand. This section will analyze these typical materials, define how sustainable these are, and make some recommendations about each material. The analysis is based on the general properties, environmental effect, life cycle, and availability of the materials in Thailand.

The following selected materials are basically fire-resistant and commonly used in Thailand. They make up the four major parts of the building: structure, walls and fences, roofs, and other building components. The structure group includes reinforced concrete and steel, which are the top two structural materials. The materials for the masonry group, such as the walls and fences, are brick, concrete masonry unit (CMU), and lightweight concrete block. Roof materials such as clay, ceramic, and concrete tiles are very common for most buildings, especially houses. Finally, other building components such as glass and gypsum board are also very necessary for modern architecture.

Concrete

Concrete is a common construction material for many kinds of buildings around the world. It has been used since the days of Ancient Egypt and the Roman Empire. It is known widespread for its compressive strength, resistance to fire, durability, and moderately low cost. Moreover, concrete can be formed into any shape with a variety of textures and surface finishes. It is made by mixing cement and various mineral aggregates, mostly gravel, with sufficient water. Cement binder is the base component of concrete. When cement mixes with water, it is called cement paste. When cement paste is mixed with sand it is called mortar. Concrete is the mixture of mortar and mineral aggregates. In addition, steel reinforcement is always added to handle the tensile and shear stress.

Use in Thailand

Reinforce concrete construction is one of the major building types in Thailand. More than 80 percent of new construction includes concrete in some part of the building, Most of the modern houses in Thailand use column and beam structure. Concrete, as a major material for construction, is used with masonry for both exterior and interior walls. It is in higher demand than wood because wood is seldom cut and is much more expensive than concrete. Concrete is in higher demand than qualitative steel because the steel needs to be imported. It can be said that concrete is a very necessary material for every kind of construction in Thailand from roads, bridges, and small shelters all the way to sky scrapers. Moreover, concrete is always used in residential, commercial, and office buildings.

Figure 9: Bai-Yok II, the highest concrete building in Thailand.

Concrete can be used in any part of a building such as foundations, footing systems, columns, floors, walls, beams, roofs, and decorated elements. Although concrete is used widely in the designs of many types of buildings, some buildings with exposed concrete do not have an elegant appeal because of less experienced laborers or from using the wrong techniques in construction. This reduces the building's value a great deal. Other materials can be experimented with to make the exposed concrete walls and finishes more appealing to the eye, and concrete can still be used for the main structure in the footings, columns, beams, and floors.

There are two large cement industries in Thailand to serve the large demand. These are established in the middle of Thailand closest to the largest limestone mine located in Saraburi province. This saves transportation costs and makes it easier to serve building sites all over the country. Cement industries are a major Thai industry that produce more than enough cement for both domestic use and for neighboring countries. In 2001, 63 million tons of cement products, including cement powder and cement grain, were produced. Of this amount, only 20.64 million tons were used in Thailand and 17.33 million tons were exported. From 2002 to 2004, economic hardship caused construction to slow all over Thailand. Large surplus amounts of cement, about 25.03 million tons, were produced, wasting a lot of energy in the production processes. The Thai government now encourages and supports the construction business to balance the supply and demand of the market. Unfortunately, this has not proved to be a good solution. More construction projects require a lot more cement for their construction which causes the cement industry to produce more products. This cycle of consumption is very serious and will only get worse in the future.

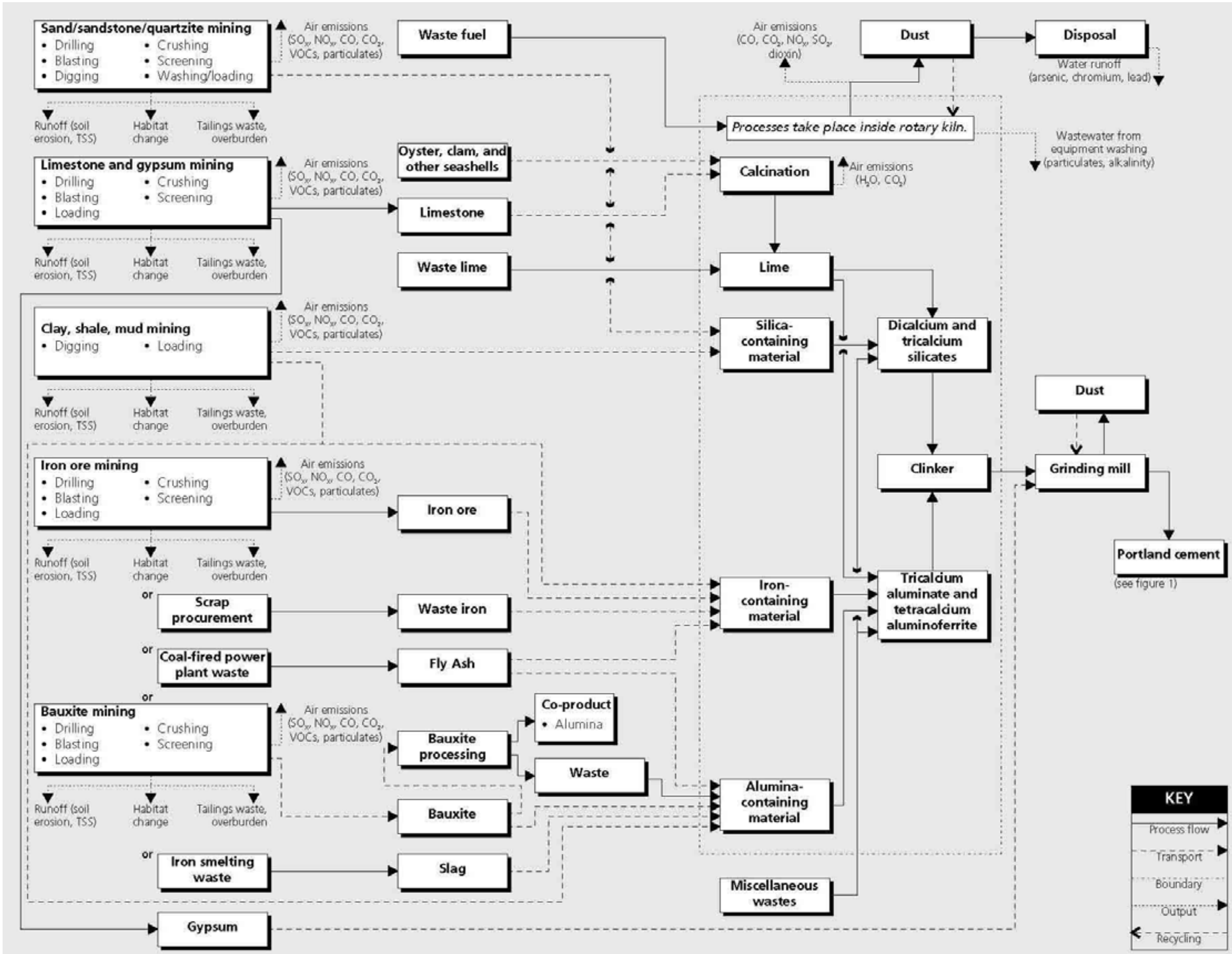

Figure 10: Life cycle of Portland cement *(The Environmental Resources Guide, 1996)*

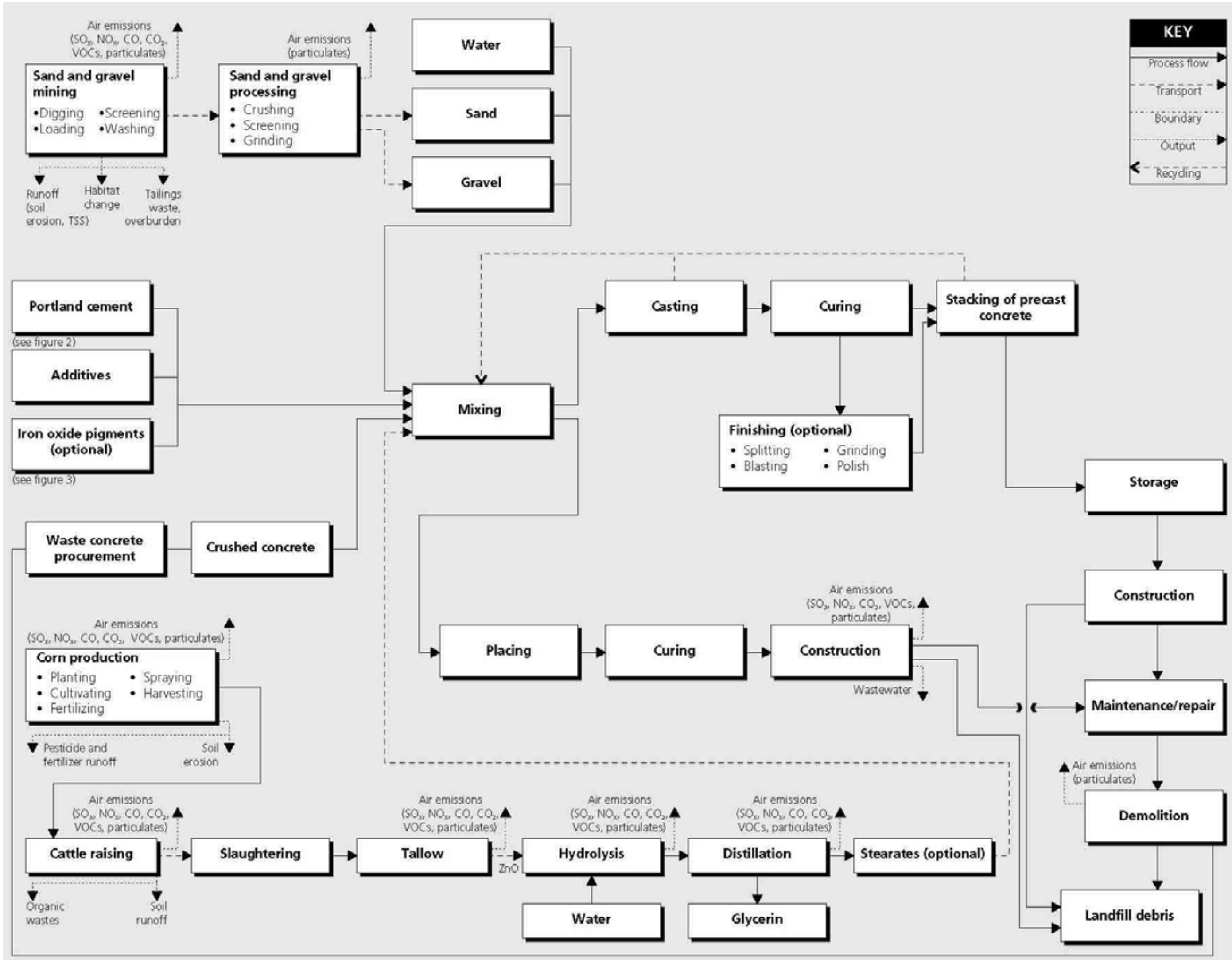

Figure 11: Life cycle of concrete *(The Environmental Resources Guide, 1996)*

Physical properties

Concrete is a compound material made by mixing cement, sand, aggregates, and water in an exact ratio. Each component has its own unique function. Cement paste fills the space between aggregates. It resists water and gives strength to concrete when it becomes hard, while aggregates give concrete low volume-change. The approximate density of concrete is 2400 kg/m3 and it has a very high compressive strength. Its PH balance is a base. Damages to concrete may be fixed but will not look like the original. It is a good fire-resistant material. It has durability and concrete buildings can exist for more than 100 years. On the other hand, concrete cannot be reused or recycled. Though material waste from industrial processes could be returned to the beginning of the process; waste from construction and deconstruction usually goes straight to the land fill.

Recently, the use of recycled and reused materials as concrete ingredients is gaining popularity due to increasingly stringent environmental legislation. The most conspicuous of these is pulverized fuel ash, recycled from the ash by-products of coal power plants. This has a significant impact in reducing the amount of quarrying and the ever-depleting landfill space.

Production process

Concrete has three major components: cement, aggregate, and water. Air is always included in the concrete volume when major components are mixed. Other admixtures are added in the concrete to modify the quality and change the characteristics. For example, some can increase strength, reduce time required to set, and increase water-resistance. The components' weight percentage and main contents are shown in the following table.

Table 2: Main contents of concrete by percentage

Components	Weight percentage	Main contents	Notes
Aggregate	70%	Gravel, sand, crushed stone, and crushed concrete	-
Cement	10%	Port land cement, supplementary cementation material	Coarse and fine material
Water	15%	-	Binding material
Air	up to 8%	-	-
Other	n/a	Admixture	Modify concrete characteristic

Portland cement is the fundamental component in concrete. It is a combination of limestone (75%), gypsum, shell or chalk, and shale, clay, sand, or iron ore. These materials can be found in mines and as by-product materials. In cement mixing, there are two different methods: dry and wet. In dry mixture, raw materials are mixed in exact proportions and then ground to powder, blended together, and fed to the kiln, still in a dry state. Alternatively, wet mixture creates slurry which is formed by adding water to the proportionate raw materials, and then the materials go through blending and grinding processes to begin the mix up process in a dry state.

Aggregate in concrete mixtures is always gravel and sand. The other choices use by-products from manufacturing like the following: fly ash from electrical coal power plants; fine sand waste from mining operations; crushed solid-waste concrete; and blast slag furnaces.

Figure 12: Concrete construction in Thailand

Figure 13: Concrete can also be used as decorated façade

Environmental effects

Concrete consumes a lot of energy from mining, industrial processes, pre-construction, construction, and post construction. Energy use in the acquisition and preparation of raw materials for Portland cement is mainly in the form of the electricity that provides power to the raw mill, the primary and secondary crushing equipment, and the various motors associated with the blender, the conveyor belt, and the dust collector. Approximately 25 percent of the total energy used in a cement plant is for grinding raw material. The ready-mix concrete has an embodied energy ranging from 1,137,713 to 2,594,338 Btu/cu yd (1570 to 3580 MJ). This number is taken from the Environmental Resource Guide which is based on American data. Thai concrete, which is produced in a production line very similar to America's, should be about the same.

Natural limestone, gravel, sand, and crushed stone are mined from a surface deposit which causes exploitation of natural resources, destruction of natural habitats, and soil erosion. The wash process during mining causes waste products such as dust, waste water, and air emissions, all of which cause pollution that could damage health.

The manufacturing processes required to produce Portland cement release chemicals into the air. Five major negative environmental impacts are;

(1) **Carbon dioxide emission.** 1 to 1.25 tons of CO_2 is released into the atmosphere for every ton of cement produced. This contributes to the greenhouse effect and global warming.

(2) **Particulates: dust and cement kiln dust (CKD)**. Dust is produced both during the grinding of clinker into cement and during the operation of the kiln. This dust could be recycled into the process, but even if this is the case, the dust needs to be carefully controlled. This dust can contain chemical elements, and it needs to be strictly controlled to avoid potential hazards inside or outside the cement plant.

(3) **Non-particulate pollution: wastewater and air emissions.** An average kiln produces about 40 tons of cement clinker per hour along with about 120 tons of exit gases, including water. Wastewater is mainly produced by washing equipment. It usually contains chemical elements.

(4) **Dioxide**. The dioxins and hydrocarbons in dioxide produced in cement plants contribute

4% of the total U.S. dioxins air emission.

(5) **Waste fuels, toxic emission, and air emissions.**

In construction, use, and maintenance stages (excluding solid waste concrete during construction), indoor air quality may be reduced by concrete products. Concrete has been proven to act as a sink and a source for emissions of some organic compounds.

Another problem in using concrete is that the construction leaves a large amount of concrete waste during and after construction. This is due to the dried concrete which can neither be reused nor recycled. Solid waste can only be deposited in a landfill or recycled by crushing and remixing. Although reusing solid waste concrete can reduce the ill effects on the environment, some chemical components in concrete that are disposed in landfills could still harm the environment.

Figure 14: Waste concrete goes to land fill

Alternative materials

Concrete is a plastic material that can be molded into different shapes. This is a strong characteristic that no other construction materials could replace. However, some components such as aggregate could be replaced by **recycled materials** like crushed concrete or **by-product fly ash** from coal power plants. These materials would not disrupt the environment and would also save a lot of energy in the mining process. Similar to the components of Portland cement, the major concrete element, **by-product gypsum** can replace the real gypsum without affecting the quality. In addition, limestone is plentiful on the earth's surface, and using **waste limestone** from construction sites in cement production instead of mining could also save a lot of energy.

Recommendation for concrete

Concrete consumes a very high amount of energy and causes a lot of harm to the environment. It can easily be said that concrete is not a green material. It is actually very far from being a green product because of the effect it has on the environment. But because of the benefits of building structures with concrete, it is certain that we cannot stop using it as a construction material just yet. However, the following are some recommendations to increase the sustainability of concrete: (1) Concrete should be used only in practical places so that the demand of concrete will decrease. That means that at least some of the environmental problems caused from this material will be reduced. (2) If using concrete in site work cannot be avoided, by-products like fly ash or crushed solid waste concrete should be added in place of aggregates. (3) In terms of raw material, concrete industries should use recycled products and by-products as much as possible.

Masonry

Masonry is the wall structure made from individual units laid and bound together by mortar. Unit masonry is structurally most effective in compression. Masonry is normally highly durable, but its durability ultimately depends on the material, mortar, pattern and workmanship. An individual unit is made from both natural and manufactured products.

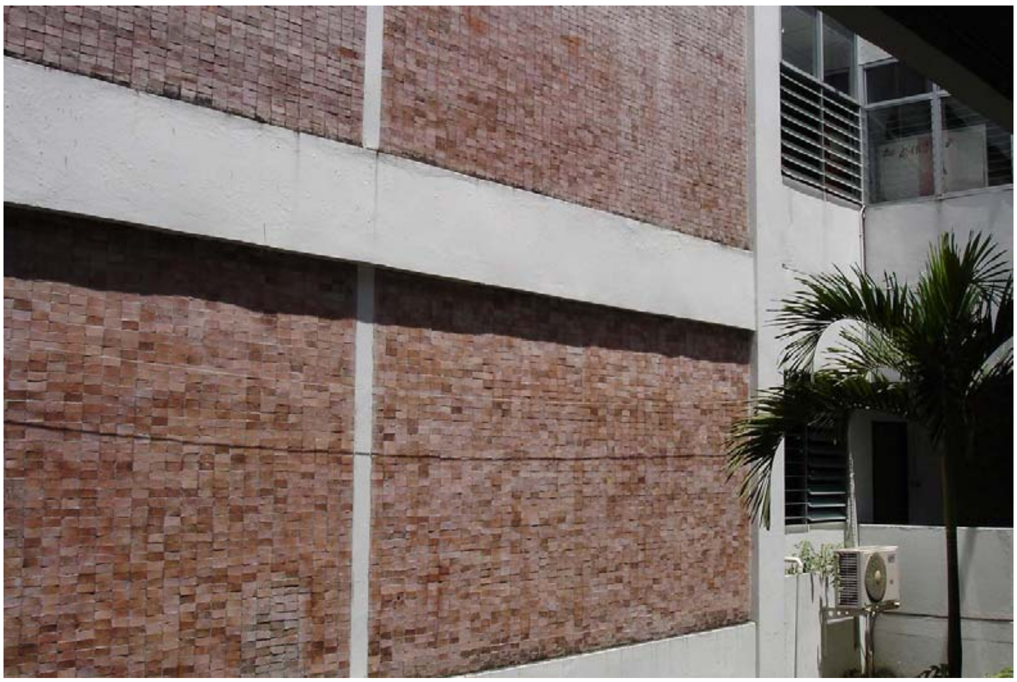

Figure 15: Showcase masonry

Use in Thailand

In Thailand, masonry walls are very well known and are used in most housing projects. The walls are usually finished with silica cement paste to make the surface smooth and clean, and after this hardens, paints are applied. Some buildings are designed in order to showcase aesthetic masonry bonding but these jobs need highly skilled workers and actual standard-sized units.

Figure 16: Masonry walls in Thailand are usually plasterd

The common materials used for masonry are brick and concrete blocks. In addition, lightweight concrete blocks are often used and encouraged by the government. Brick, concrete block, and lightweight concrete are all masonry units and each offers its own advantages and disadvantages.

Masonry units can be produced by two basic methods: one uses heat (bricks) and the other uses chemicals (concrete masonry units and lightweight concrete blocks). Using heat offers a natural way to create clay bricks by pressing clay into a shape and burning it. The other method for producing concrete and lightweight concrete is through a chemical processing of combining cement, crushed aggregate, water, and other admixtures which are then cast in a block.

Brick

Brick in Thailand has been used since ancient times to make palaces, temples, and city walls. The age-old knowledge and skills to make brick has developed over time. Today, brick laying is still the most accepted method for wall systems, both interior and exterior.

This is true for every kind of building including social, commercial, and residential uses. When using a column and beam structure, most brick walls in Thailand then become non-load bearing walls. Two of the major brick types used are industrial brick, which is of the highest quality and higher price, as well as local brick.

Figure 17: A workman using smooth finishing to cover the brick wall to create a neat appearance

Physical properties

Bricks are made of rigid clay-based materials that gain strength after they are burned. Most of the bricks in Thailand are orange in color. The standard size for a brick is 7.8 x 19 x 6 cm, but the actual size will differ slightly from the standard size depending on how the bricks are produced. Bricks from the high quality producers are very close to standard size and are also the strongest. Stronger bricks allow for a more solid structure, but some bricks cannot withstand the weight of the building. Bricks have very good compression-resistance and they are very durable, especially after construction. Due to its small size, bricks can easily be laid in sharp curves or patterns for an aesthetically appealing structure.

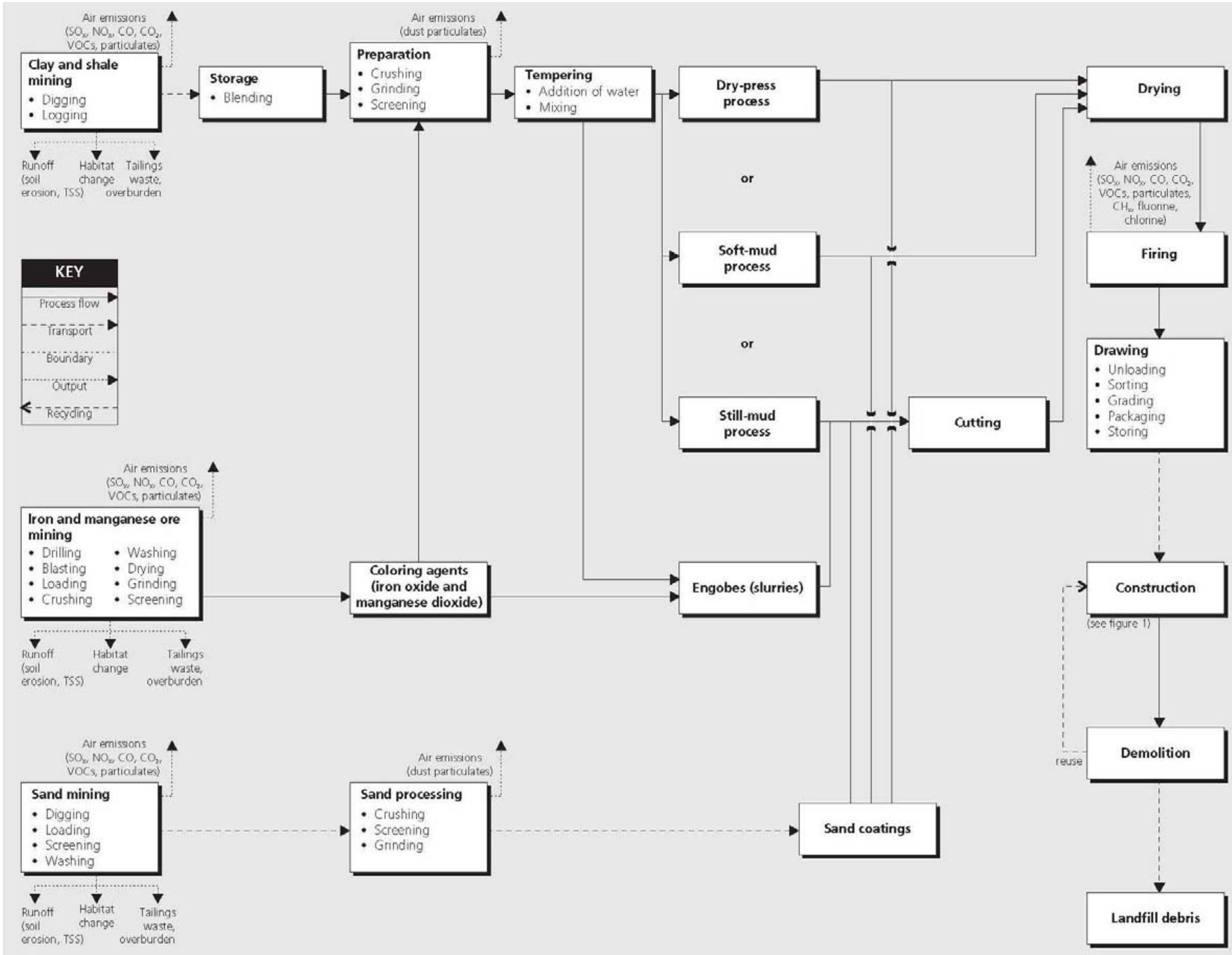

Figure 18: Life cycle of brick *(The Environmental Resources Guide, 1996)*

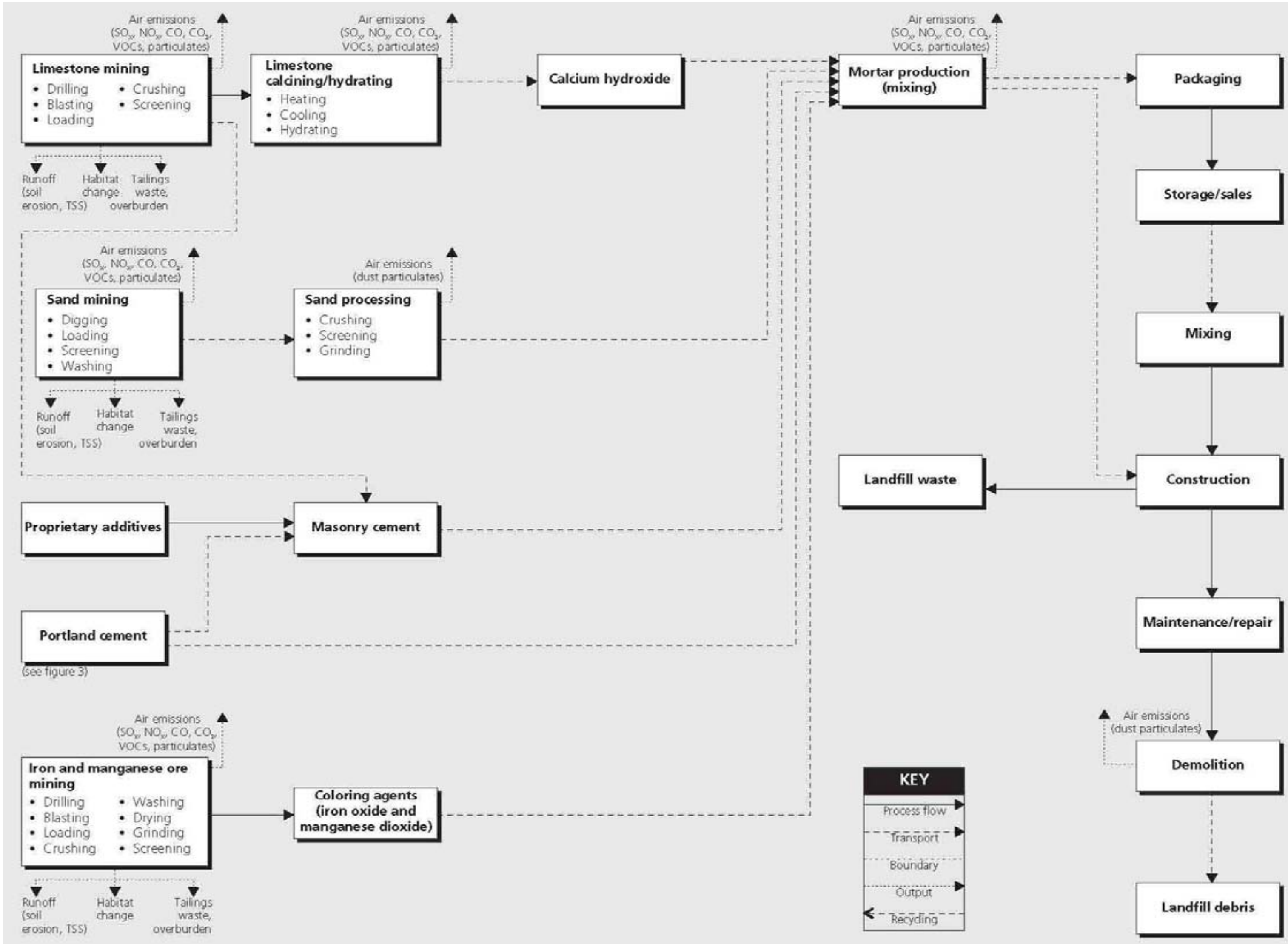

Figure 19: Life cycle of mortar *(The Environmental Resources Guide, 1996)*

Production process

In the past, brick in Thailand was only made from a mixture of clay and husk that was pressed into shape, sun dried, and then burned to make it stronger. Today, the local brick (typically cheaper) used in non-loaded bearing walls is still made using the same method. The husks from rice fields are added to reduce weight. After burning, the husks provide good bonding and also act as a heat-insulator. The local brick is used for the lower-cost projects in each local area and are usually made with locally produced raw materials. The skills for using brick in construction have been devolved through generations. In some areas, there is an abundance of good quality clay used to make brick, which allows some local brick producers to develop a reputation for higher quality bricks.

Alternatively, industrial bricks have higher quality materials in their mixture and are produced according to a more accurate standard size. This kind of brick is made from compressing clay (with no husk) with a pressing machine. The machine provides the uniform standard size which is 11 x 24 x 7 cm which allows the bricks to fit together well and can therefore be used in showcasing the bonding work of masonry that was mentioned earlier.

Some other kinds of bricks that are used in Thailand are decorated-bricks, fire-resistant bricks, and cement-clay bricks. Each type of brick is produced in a different way and has its own individual purpose.

Environmental effects

The husk used to make local brick in Thailand is farm waste and is mixed with clay to reduce the volume of clay used in each brick. The husk acts like a bond to make brick stronger and lighter. Using the husk is an excellent way to reduce waste and reduce the amount of clay needed to make bricks. Some energy is necessary for the cool-down process. It is necessary to dry the brick before firing it. Sun drying is the best way to save energy and this method is used most often for local brick production but it requires large areas and lots of workmen. The largest negative effect the brick-making process has on the environment is not during the casting but during the firing of the bricks. Wood and fuel are used to burn the cast clay. Many kinds of air pollutants are released during the burning such as carbon monoxide, nitrogen oxide, chlorine, and sulfur oxide. Another thing to note is that it is not economical to transport brick because of its heavy weight.

Concrete block

In Thailand, Concrete Masonry Units (CMU) and cement blocks are also known as concrete blocks and are usually bigger than clay bricks. This size difference makes concrete block faster and easier to lay for a wall structure than regular brick. The advantages to using concrete block are that it is easily produced and inexpensive. It is most often used for fences, industrial building projects, or for structures where appearance is not important and low cost building is desired.

Figure 20: Concrete masonry unit or concrete block wall

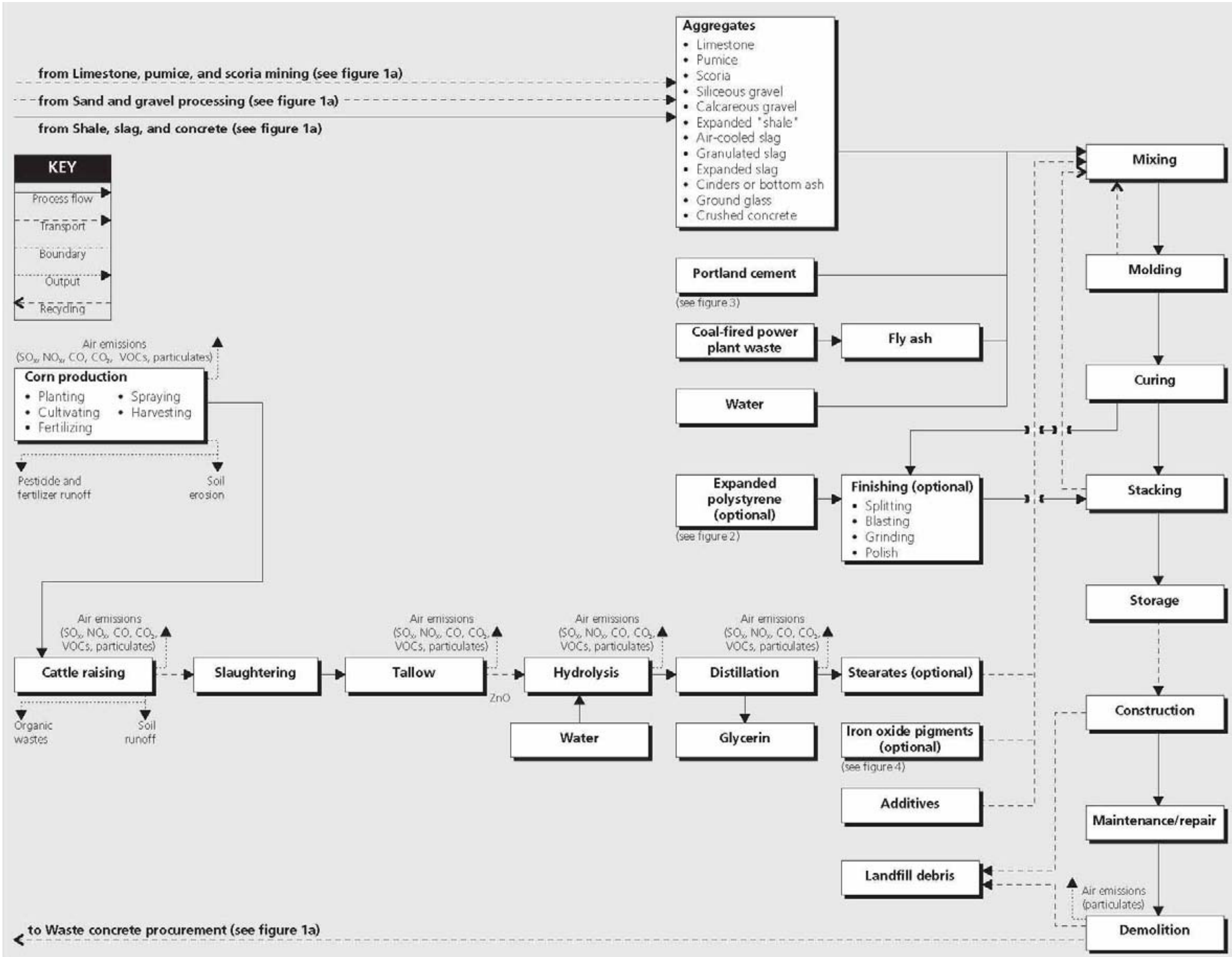

Figure 21: Life cycle of concrete masonry unit or concrete block *(The Environmental Resources Guide, 1996)*

Production process

Concrete masonry units are always known as concrete blocks or cement blocks in Thailand. Cement block is the mixture of sand and cement, but concrete block is made from stone crushed to a powder and cement. Both of them have the same easy production process after mixing. The mixture is pressed or cast into the desired shape. After it sets, it must cure for around seven days before it is used.

Although concrete block is quite similar to concrete in its components; unlike concrete it can be transported to a construction site in individual units that are already dry and can be used immediately.

Figure 22: Concrete block construction

Environmental effects

Basically, concrete block is concrete that is prefabricated into a solid block. It uses the same raw materials that concrete uses and has many of the same effects on the environment. The energy required to produce one typical concrete masonry unit is less than concrete, estimated to be from 22.5–30.6 MJ.

Light-weight concrete block or AAC

Autoclaved Aerated Concrete (AAC) is an inorganic construction material used for solid walls. It is also known as light-weight concrete block. The significant thing about this material is that it contains a lot of tiny disconnecting air pockets that make up 75% of the block's volume, which decreases the construction load. Moreover, when compared with other masonry materials, it has the best ability to resist heat and moisture.

The disadvantages of AAC are the price and AAC layering. Although using AAC is very widespread today, it is still more expensive than brick. This could be due in part to the fact that laying AAC is relatively new. It is also only produced by a few manufacturers because it requires special mortar and specific tools. For this reason, the few competitors in this field have formed a monopoly and have raised prices. In addition, using the special mortar requires highly experienced workers in order to create a thinner coat than with other masonry. There are very few workers who have experience with this and have become skilled in working with the thin plaster. Because of this, typical AAC jobs at present are not as neat as they should be.

Physical properties

AAC is a durable noncombustible material. The approximate weight is around 400-600 kg/m^3 (Concrete is 2400 kg/m^3). Its capacity is 2.5 times less than brick because AAC has a very high heat resistance and desirable acoustic qualities. It is not a thermal mass but it is insect and moisture resistant. AAC standard size is 20 x 60 cm which varies in thickness from 7.5, 10, 12.5,15, and 20 cm. AAC with a thickness of 10 cm can resist fire for four hours and absorb noise up to 38 decibels. The larger size of AAC compared to common brick also cuts down on the time required to lay the masonry.

Production process

AAC is made from a particular mixture of cement, sand, lime, gypsum, and aluminum powder which causes air bubbles. To create air bubbles in the mixture, it must be cured in high pressure steam.

In Thailand, AAC block has been produced for more than five years by two different companies that both get their material knowledge from Germany. They are located in the middle of Thailand near the capital city of Bangkok. This is also where the major cement producer is located.

Figure 23: AAC construction – the mortar between each block is thinner than in other masonry materials

Environmental effects

AAC is well known as an environmentally friendly construction material. The raw material consumption is very low for the amount of finished product produced. In the manufacturing process, no pollutants or toxic by-products are produced. AAC is also completely recyclable.

AAC helps reduce the energy consumption of buildings by being an excellent insulator for both heating and cooling. AAC, a low thermal capacity material, does not collect heat during the day or release it during night. For Thailand, this attribute could reduce energy used for air conditioners or even make air conditioners unnecessary. AAC releases no toxic substances during or after construction. This makes it safer for indoor use because it also reduces the risk of fire.

Recommendations for masonry

To determine the most appropriate material for a particular building project, one must evaluate the following factors: physical properties, the type of work being done, cost, the availability of raw materials, and the processes involved all the way from manufacturing to the finished building.

Due to its physical properties, AAC is more appropriate for Thai buildings than other masonry materials. Many Thai researchers have said that AAC is a new brilliant choice for every kind of energy conserving building in Thailand. Compared with concrete block and brick, AAC is the best heat insulator and does not retain heat. This is dissimilar to the thermal mass of brick and concrete block, both of which hold the heat in from the sun and release it at night. The lightweight of AAC makes the building lighter, which reduces stability reinforcements and reduces costs all around. In addition, it can reduce the amount of concrete used in the building.

Other factors that are important to consider when choosing the most appropriate material are cost and type of work. AAC has the highest level of quality and the best physical properties but it comes with a higher price. Some building projects cannot afford to use AAC because of its higher cost. Brick and concrete block are better options when cost is the deciding factor.

Concrete block is good for use in the building of fences, factory walls, elevator shafts, garages, or low-cost buildings. Fences do not need to offer any insulation but instead should be inexpensive, easy, and quick to build.

Therefore, the high thermal capacity in brick is not appropriate for a residential building because it would release heat during the night and create discomfort for its inhabitants. Brick is very good for daytime-purpose buildings in Thailand including temples, some commercial buildings, and schools. Brick can hold the heat during the day while keeping the interior cool.

Steel

Since the Industrial Revolution, steel has become one of the most important materials. It is not only used in industries but also in construction. It is used widely to create high-rise buildings, bridges, and other large structures which concrete, brick, or other traditional materials could not do. Steel could also be used for structures like columns and beams, framing for walls and roof, or rebar in concrete construction.

Figure 24: Steel as main structure in Thai national airport terminal building

Use in Thailand

Steel manufacturing, one of the primary industries in Thailand, is very important to the country's development. Steel consumption reflects the country's economic status as well as the gross domestic product (GDP). The steel industry is utilized in construction, vehicle, furniture, appliance manufacture, and packaging, etc.

According to the Federation of Thai Industries report (2005), more than half (58%) of steel consumption in 2004 is in construction (7.486 million tons). In construction, steel is commonly used for rebar, structure and frame. **Reinforcing steel** is mild steel normally used with concrete to improve the tensile strength of the structure. There are two types of rebar: RB for small construction and SD for medium or big sized construction. Next, **steel used for the structure**, such as I-beam and H-beam are high quality steel. It could be used without concrete or other finishing, but it could also benefit from additional rust-resistant coating. Presently, steel structure housing is becoming more popular because it is time saving and durable. On the other hand, it is more expensive than concrete because of its higher quality. Steel structure construction takes a shorter time compared with concrete construction. While concrete construction requires 28 days just to cure the concrete and meet the desired strength in each part; with steel structure, everything could be finished in 45-90 days. The last one is **steel for frames, studs, or joists,** which usually comes in hollow pipe, hollow box, or angle shapes. Steel framing is steadily increasing because it is inexpensive and could replace wood frames for walls and roofing. Steel framing is also more durable and lighter than concrete construction.

In the last three years, the price of steel has become prohibitive. Although the Iron and Steel Institute of Thailand promote the use of steel and encourages people to use it for their houses instead of concrete, the Thai government is not supportive. The government has not allowed the import and open trade of steel and thus, the price for domestic steel has increased by more than 100 percent in one year (from 2003 to 2004). Consequently, this situation indirectly benefits the cement industry.

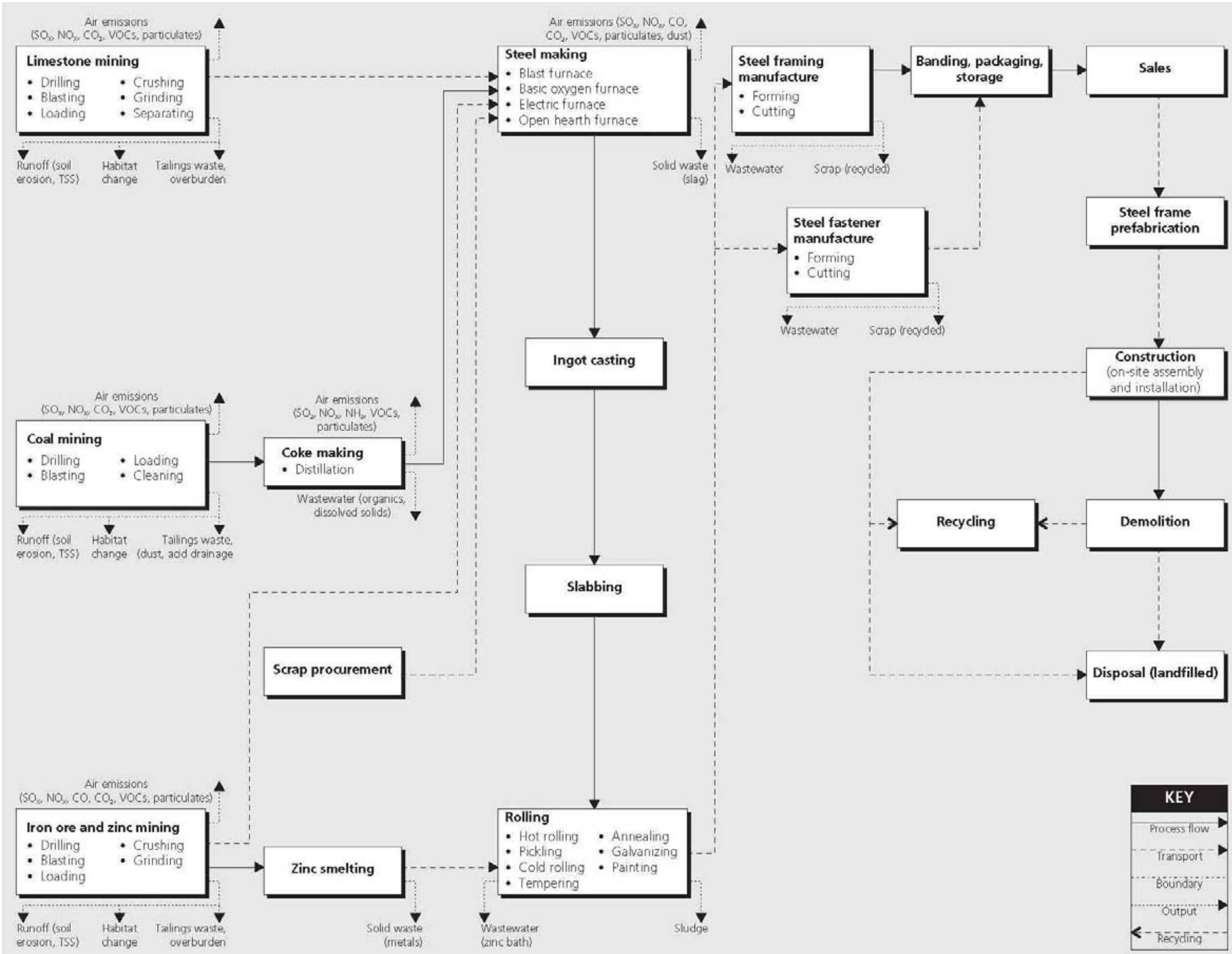

Figure 25: Life cycle of steel *(The Environmental Resources Guide, 1996)*

Physical properties

Steel is a very durable material, which is used in important parts of construction such as the structure and framing. Steel is also fire-resistant for two hours or more. It is malleable and thus could be formed into practically any shape. In addition, it can also be cut, bent, and welded on the construction site. With ease of transport and reassembly, wood and masonry have been normally replaced by steel stud, joist, and framing. Steel provides very high tensile and compressive strength. Rebar steel is commonly added in concrete construction to improve the ability to resist the tension load, while the structure steel, I-beam, H-beam, or C-shape could be used without other materials. Steel has the highest potential for recyclability compared with other materials. Scrap steel could be recycled, reused, and reshaped. The overall recycling rate for steel is 66%.

Figure 26: Steel roof framing and aluminum frame for ceiling

The only major concern of using steel is rust or iron oxide which is caused by oxidation when steel comes into contact with moisture. An additional rustproof coating is required in cases where steel is used without a cover.

Production process

To make steel, some natural materials such as iron ore, coal, and limestone are required. Iron is the second most abundant metal, constituting about five percent of the earth's crust. In Thailand, Hematite (Fe_2O_3) containing 70% iron is found in the mountain ranges that traverse the entire Western part of the country. Limestone is used as flux to separate the iron from other minerals. Coal is the fuel in the steel smelting stage.

There are three major phases in making steel: the primary, secondary, and final phase. The primary phase is material acquisition and preparation stage. Raw materials are smelted in a blast furnace in a temperature from 2,200 to 2,400 ^{o}F which become pig iron and are then cast into ingot. The secondary phase is slabbing, rolling, and shaping. Air pressing is a process that increases its sturdiness. Hot or cold rolling, pickling, tempering, annealing, galvanizing, or painting could be done in the rolling process. The final phase is mostly forming the framing steel, pressing the rebar steel, and cutting the steel into desired shapes. Then bending, packaging, and storage are done before sale.

Thailand usually imports pig iron for construction purposes from China. Although iron and limestone are plentiful in the country, the primary phase needs expertise and huge investment. Most investors are interested in the secondary and final phases which use lesser energy and have higher market demand. Presently, Thailand has decreased its importation of steel and circulates steel in the country by using recycled steel. The government raised the price of imported steel, arguing that the steel in the country is enough for every purpose.

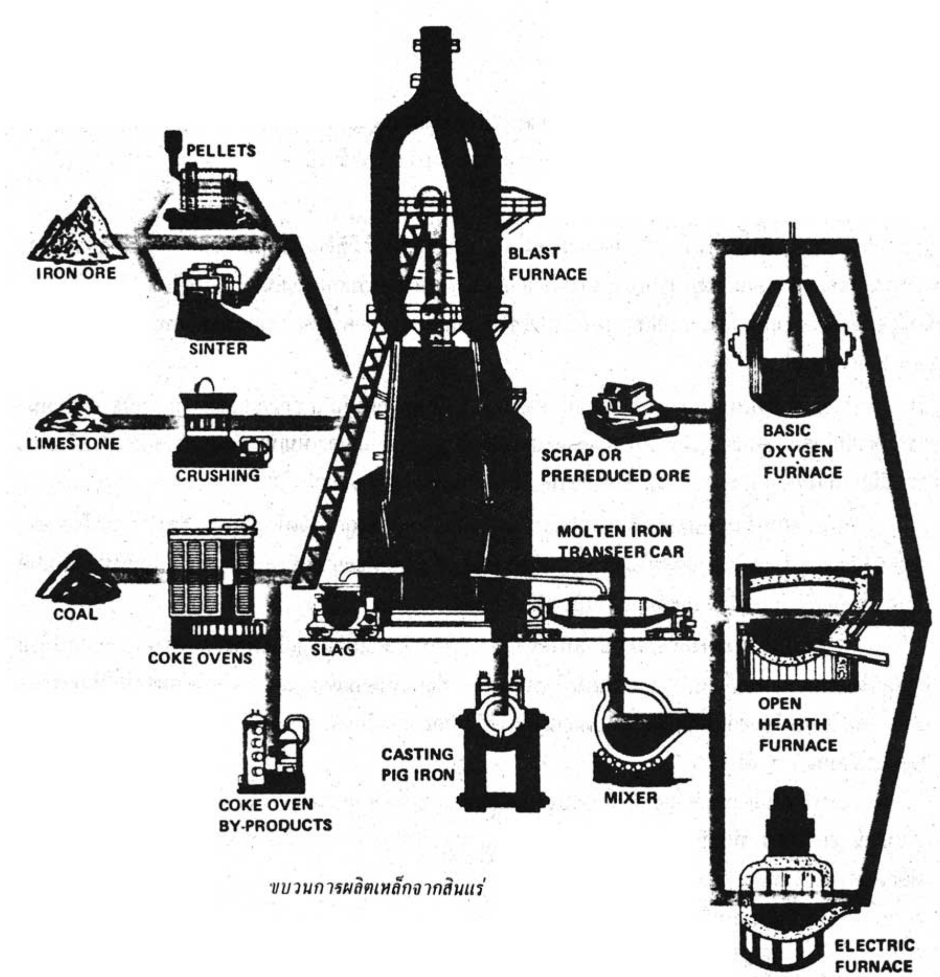

Figure 27: Steel making processes

Environmental effects

Energy usage in the initial production of steel is intensive. Up to 9,200 Btus/lb of product is the approximate total embodied energy used in producing steel framing. The number could be reduced by 39% if the steel productions were made from scrap instead of the raw material, which uses a basic oxygen furnace in the primary phase. Using recycled steel conserves energy of up to 5,450 Btus/lb. In addition, scrap steel recycled over the past ten years has resulted in the reuse of 1.2 trillion lbs of steel (ERG, 1996) in the US and abroad.

Like other materials, mining limestone, iron, coal, and zinc poses risks of soil erosion, land degradation, and habitat loss. A huge amount of water is consumed to extract the raw materials and to manufacture steel. The wastewater after the manufacturing processes is polluted and might be released to nearby water sources. Producing steel releases dust, particulates, and harmful air emissions like SO2, NO2, and CO_2, but gas from burning coal in the smelting stage could be used for other industries such as dyes and fertilizer. On the other hand, after the production phase, steel products do not release any other air emissions which could impact indoor air-quality.

Recommendation for steel

Steel is the recommended material for Thai building. It is very durable and has many functions. It can also be assembled very fast and uses a cleaner and safer drying system. The waste steel from construction sites can be returned to the manufacturing stage. Although its production uses high amounts of energy, subsequent manufacturing processes are much lower. The high potential recyclability of steel makes it more sustainable than other materials.

At present, steel in Thailand is very expensive which does not make it economical and suitable as the main structure in small construction sites. However, using steel structure for big construction sites is better than reinforced concrete due to its lighter weight, shorter construction time, high rise ability, and larger span. In addition, steel framing, studs, and joists can replace expensive wood and forests can be conserved.

Glass

One of the most important, valuable, and beneficial construction materials found in every building is glass. Glass is a transparent material allowing light, heat, and also a view of the outside world into interior rooms. It is durable, fire and water resistant, and recyclable. Moreover, glass gives aesthetic value and luxury to the design. With these qualities, it is generally used for windows, doors, and curtain walls that need open views. There are various types of glass for different qualities, purposes, and processes. The following are examples of these different types of glass:

Float glass	Clear glass
	Tinted glass
Heat treated glass	Tempered glass
	Heat strengthen glass
Surface Coated glass	Solar-reflective glass
	Low-E glass
Processed glass	Insulated glass
	Laminated glass
Others	Mirror
	Pattern glass
	Wired glass

Use in Thailand

Thailand first produced glass in 1963 to reduce importation. In the beginning, only one glass industry existed. This was the corporation jointly owned by a Thai and Japanese company. In 1990, another glass industry, a corporative between Thai and America, was established. The glass industry increased rapidly following the economic boom from 1990 to 1997. Today there are four glass industries, but the two mentioned large industries still produce the most glass and have a huge market share. The marketing structure of the glass industry in Thailand is very similar to the cement industry because there are few competitors, although some glass is imported from Indonesia.

Figure 28: Glass as skylight and wall at the new Thai National Airport

Glass in Thailand is most often used for windows and doors in the common buildings like houses, and for cladding walls in commercial and high-rise buildings. Sometimes glass is used in a skylight. Skylights are not commonly used because they let in undesired sunlight, causing the building to be hotter than normal.

Although there have been many kinds of glasses invented, only a few types are frequently used in Thailand, each for its own individual reasons. **Clear glass** is the cheapest and most highly demanded type of glass. It is 88 percent light transparent and allows 83 percent of heat through it. It combines with other featherlike film or clear glass, as laminate glass, or insulation glass to improve strength and give it the ability to protect from the heat. Clear glass is not only used for the plain window, but also for glass louvers, both of which are commonly used in Thailand. The louvered window is popular because the small size of the glass costs a lot less than a large glass plate, and it can also be replaced one plate at a time if needed.

The **tint glass** or colored glass is a translucent glass which provides different amounts of light depending on its thickness. The thickness affects the quantity of heat that can penetrate. The thicker it is, the hotter it can get, which causes more heat to pass into the room. It is similar to the heat absorbing glass in how it looks, but they are different in their properties.

One of the most used glasses is **heat absorbing glass.** It is very popular as a wall cladding. Its color comes from adding some oxides like iron or cobalt to the glass to absorb the sun's radiation energy. It could reduce 40-50 percent of the heat that would pass through the building which improves efficiency for the air conditioning in building. In addition, the heat absorbing glass offers soft light that creates comfortable vision conditions.

The next type of glass is the **reflective metallic coated glass** which acts like a mirror. It can reflect up to 60 percent of the direct solar heat, but does not do as well at absorbing the heat. It is very useful for buildings used primarily during the day because the light could potentially be reduced by 80 percent or more, creating soft light. It should be noted that while reflective metallic coated glass most importantly reflects the heat, light is reflected at the same time. However, the reflection might seriously affect the surrounding building and also vehicles on the road.

Insulated glass or double glazing encourages low heat radiation and does well at preventing the transfer of heat from inside and outside. In Thailand there are two common types of insulation: dry air and inert gas. Both require the same combination process but differ in qualification. The dry air is a very good heat insulator and insulated glass with dry air also offers better acoustics than normal glass. The inert gases resist more heat because they are low heat conductors, but it is more expensive than using dry air. The insulated glass with inert gases, normally Argon, is high quality insulated glass. It could reduce 70-80 percent of solar heat while allowing a high amount of high quality light into the room. Moreover, it could prevent ultra violet (UV) rays from coming into the room if there is a coating of film on both sides of the glass.

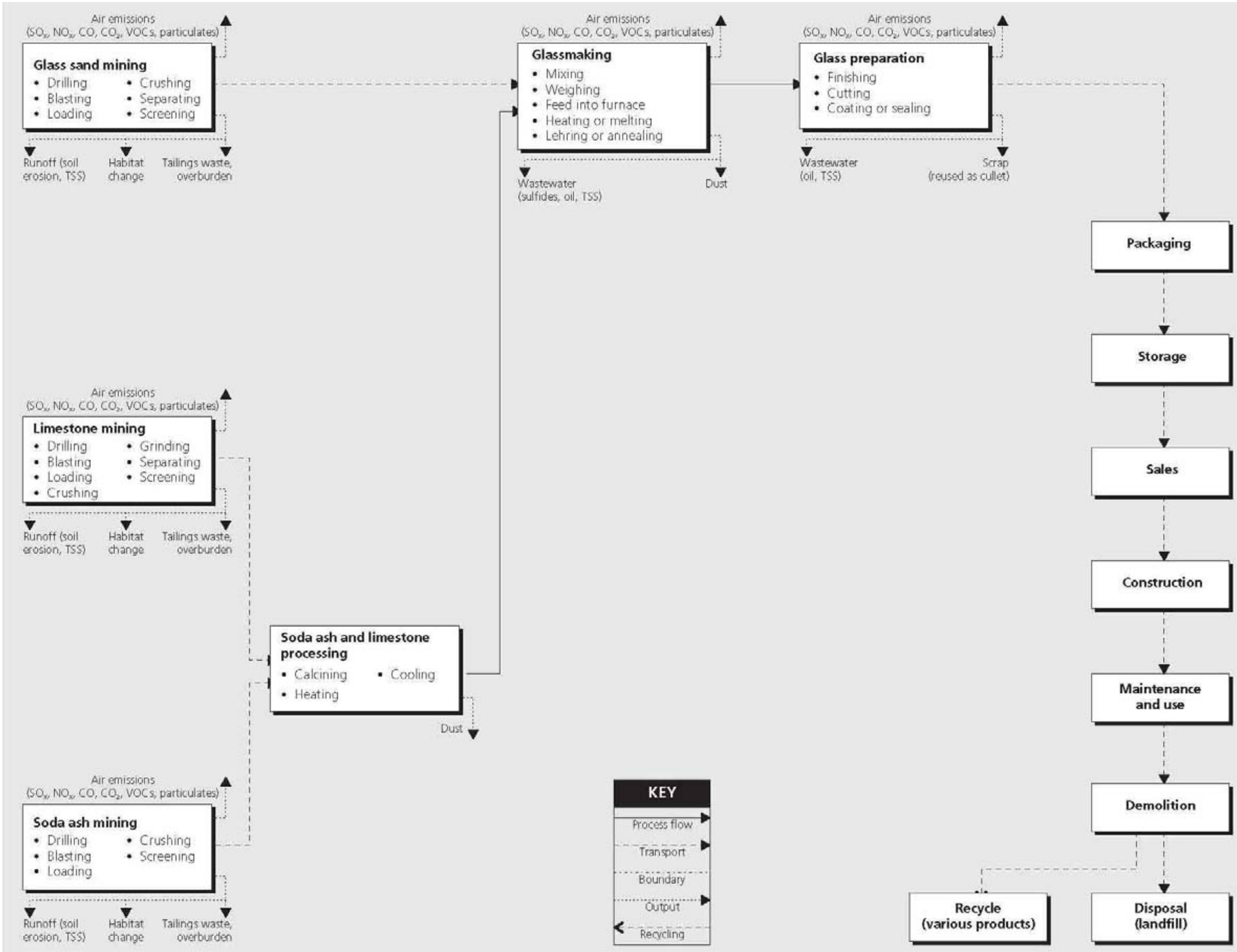

Figure 29: Life cycle of glass *(The Environmental Resources Guide, 1996)*

Physical properties

Glass comes in various dimensions. The biggest size is 3.6 x 12 meters and19 mm thick. It is a rigid and high density material and has a very durable life-cycle. Glass requires low maintenance. It is very resistant to fire, sound, moisture, and stains. It could stand tensile and compressive tensions, but not the impact. It cannot be fixed when it breaks, but it can be sent back to be recycled. The basic clear glass allows light to pass through at a rate of 75-92 percent. The more transparent it is, the more heat can penetrate. When solar short waves (3 micrometer) pass through the glass, it is transformed to long waves (3.5-50 micrometer) which cannot get passed back through the glass.

Production process

Quartz sand, the major raw material for the glass industry, is mostly found along the eastern and southern coasts, but there are only three potential locations where the sand is pure enough to produce glass. Rayong province provides about 72% of quartz sand used in the country. The sand from Thailand is not enough for construction purposes, so the Thai government controls the use of the sand and prohibits exporting quartz sand. Quartz sand is dug from sand pits and transported by truck. The sand is then separated from stones, shells, or other particles. Then, only the 20 mesh quartz sand is used in the next process.

Glass is normally made of silicon dioxide which is sometimes compounded in quartz sand or polycrystalline in pure silica. Some components such as limestone and soda ash are compounded. In addition, some metal is used in glass coating and tinting. The melting point of glass is 2000 °C (3632 °F). Sodium carbonate and calcium oxide are added during the production to reduce the melting point to 1000 °C. During production, many other chemicals can be added to increase the quality. After the glass is produced, additional techniques can be done to make the glass meet different purposes.

The glass industry uses a huge amount of energy in the production process. The machine must run 24 hours a day, only being stopped for maintenance every seven to eight years, to avoid melted glass from cooling down and getting stuck to the machine. This situation has caused overproduction because the production cannot be adjusted to fit the real demand. This problem has been the reality since 1997.

Environmental effects

According to the Environmental Resource Guide, the typical embodied energy in normal flat glass is estimated to be 13.5 to 15 million Btus (15,825 MJ) per ton. The energy consumed in mining raw material from the sand pit is 430,000 Btus per ton, 164,000 Btus per ton from the limestone pit, and 1.62 million Btus per ton from the natural soda ash mine. Besides mining, glass production loses energy also in the melting and cooling processes. In fact, 99 percent of emissions released from glass plants are from melting processes, and these emissions are not threatening to the environment when compared to other production emissions. Furthermore, glass has a very long life span and requires little maintenance. Although some metal is added as admixture to improve its quality, it is a small amount when compared to the other materials.

Glass is a recyclable product. Glass made from cullet, broken, or waste glass returned for recycling, requires 30 percent less energy than manufacturing from scratch. Each ton of recycled glass replaces 1.2 tons of raw material (sand, limestone, and soda ash). Recycling one ton of glass, even from bottles or buildings, could save 150 liters of a nation's oil. More than that, it will reduce the land and cost required to dispose of the waste product. It is unfortunate that the potential of recycling glass in Thailand is very poor right now, because there is no system for retrieving the glass. Most recycled glass is only from manufacturing itself, thus nationally there is little success. Some cullet from construction sites is sent back to manufacturing, but most of it is put into a landfill. The Thai government has announced the benefits of recycling but has not given clear directions to follow. The system of waste segregation is not implemented and few recycle bins are provided in public places.

Alternative materials

Glazing is a form of technology that completely changes the style of a building and the options one is given when deciding to build. The opportunity to let light in and view the outdoors while keeping the room separate from outside is very desirable. In addressing these functions, no other building material can be compared to glass. It is in high demand and new glazing technologies are developed day to day to get higher quality and efficiency glazing products and installation systems. Besides glass, the wide-spread products in glazing are acrylic and polycarbonate.

Acrylic and polycarbonate are glazing products similar to glass. They are used for windows, walls, skylights, and decoration. When considering properties, there are some advantages and disadvantages. Acrylic and polycarbonate come in many colors and various dimensions, depending on the producer. The general size is 4 x 6 ft, similar in size to a plywood sheet or gypsum board. Both acrylic and polycarbonate sheets are lighter than glass that is cut to the same size. They can stand the force of impact, but do not have the strength that glass provides. Acrylic provides the clear view, but it always changes to yellow after it has been exposed to UV rays for long periods of time. Polycarbonate is UV resistant, but does not offer complete transparency. They are both widely used for decoration and temporary exhibition booths.

Recommendation for glass

Glass is a very green product in comparison to other materials like concrete or steel. Although producing glass releases some emissions, it is one of the most environmentally friendly products when considering the entire production process along with its ability to be recycled. Using glass conserves the building's energy and creates a higher quality environment inside the building. Recycling glass in Thailand should receive more attention from the government, producers, builders, and the general public in order to make glass even a more sustainable material.

For its properties and various types, glass is a very practical and durable product if the appropriate type of glass is chosen. The transformation of solar wave from short to long affects the use of glass. It could help warm the house with solar energy during winter, but it could also overheat the interior if not used in the right circumstance. Making a wise decision in choosing the type glass is very important, especially in Thailand where solar radiation is very high.

Gypsum board

Gypsum board is generally known as drywall, wallboard, or plasterboard. It is the generic name for a family of panel-type products consisting of a noncombustible core that makes gypsum board different from plywood, hardwood, and fiberboard. Each sheet of gypsum board consists of a hardened gypsum core sandwiched between two layers of a strong smooth-finished paper on one face side and rougher, 'natural' paper on the back. The face paper is folded around the long edges and is tapered slightly to accommodate joint tape and compound after the panel is installed. The ends of the panel are cut square and finished smooth, leaving the gypsum core exposed.

Gypsum board has outstanding characteristics that make it more suitable for wall covering than plaster, plywood, and other materials. Gypsum board is used most often for interior partitions in many types of buildings including houses, offices, schools, shops, apartments, theaters, and airports. In addition, it can be used as a composite wall with brick, stone veneer, and vinyl in an exterior wall.

Figure 30: Gypsum board ceiling in Thailand normally installed with aluminum frame

Use in Thailand

In Thailand, gypsum board is normally used for ceilings and some interior walls. While 95% of ceilings in Thai houses are made of gypsum board, gypsum board wall is not used that much. Generally, it is used for decoration, to divide spaces, and for nonpermanent exhibition booths. People do not prefer gypsum wall in their rooms because it looks cheap, is a bad sound shield, and is not as durable as alternative products.

In the market, gypsum board is provided in many types that differ in their thickness, size, and quality. There are moisture-resistant drywall, fire-resistant drywall, abuse-resistant drywall, flexible drywall, high-strength ceiling panel, and foil-backed drywall.

Figure 31: Seamless gypsum board ceiling can be found in high cost buildings

Physical properties

Gypsum board is available in a variety of lengths. It is easy to cut, install, and repair. When properly reinforced with tape and joint compound, panels are highly resistant to cracks. The panels readily accept paint and most other decorating materials. Gypsum board eliminates excessive moisture during construction, unlike plaster walls. The noncombustible gypsum core is also fire resistant. The dense panels provide excellent sound control over other light materials such as fiberboard and plywood. Gypsum board provides structural integrity. It is easy to decorate and serves as a good base for paint, wallpaper, paneling, textured finishes, decorative fabrics, and vinyl wall covering.

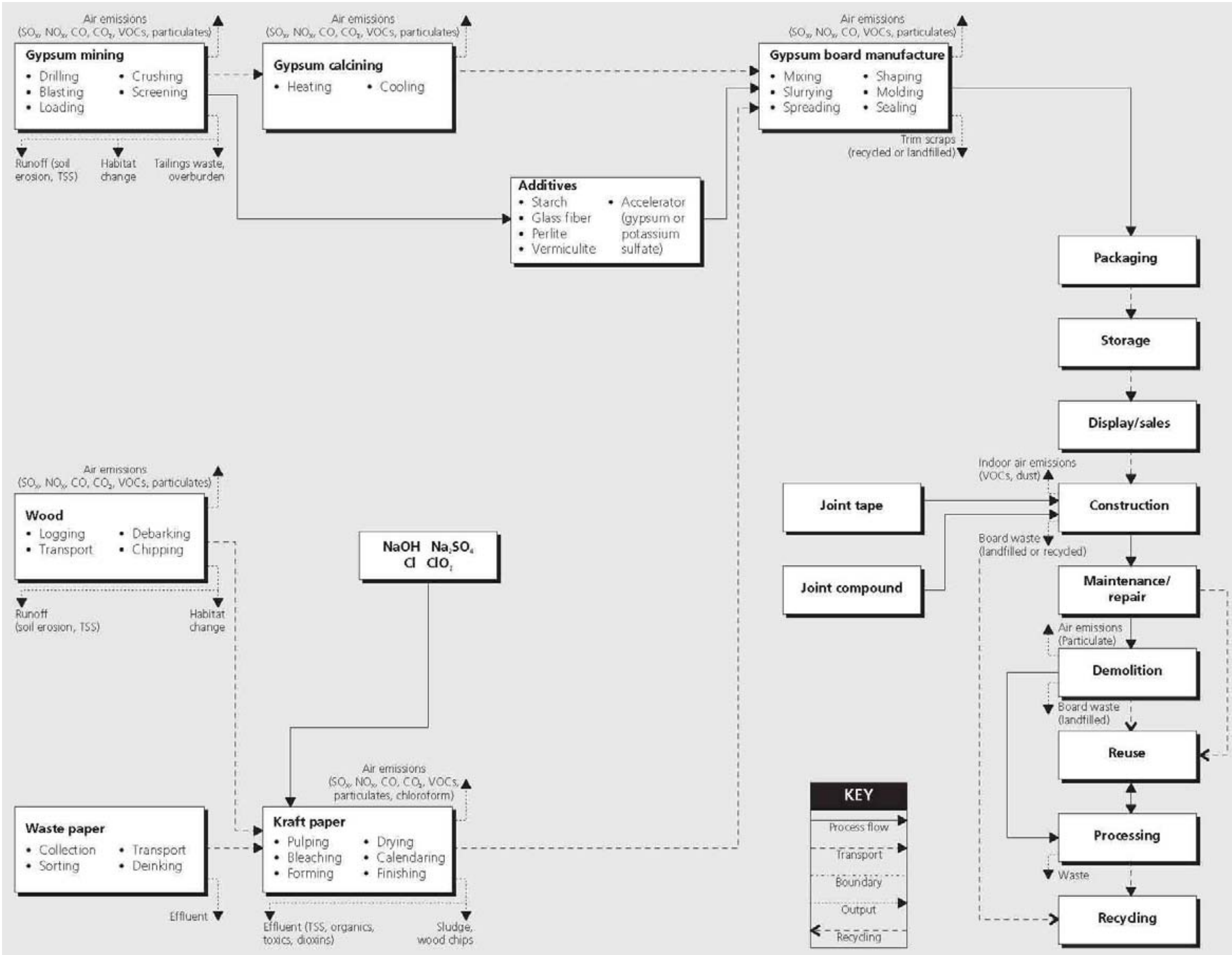

Figure 32: Life cycle of gypsum board *(The Environmental Resources Guide, 1996)*

Raw materials, mines, and production line

Raw gypsum used to make gypsum board is from two major processes. The first is crude gypsum from the mine. The second is synthetic gypsum as a by-product from other plants (Founie, 2003). The gypsum powder is readily used to make the core of the board which is sandwiched by paper. The Environmental Resource Guide provides that gypsum board's embodied energy is approximately 2,600 Btus/ sq.ft. Paper manufacturing is energy intensive, requiring about 15,650 Btus/ sq.ft., but embodied energy in paper processes could be reduced 30 percent by using the recycle paper. These numbers are the same in Thailand because manufacturing is an imported technology from America and Germany.

Gypsum is a common, non-metallic mineral found in sedimentary rock formations. It is crystalline and is known as calcium sulfate dihydrate ($CaSO_4 \cdot 2H2O$). Pure gypsum is a white-to-transparent mineral, though impurities can give the mineral a gray, brown, or pink coloration. When gypsum is heated, it loses approximately three-quarters of its water and becomes hemi hydrate gypsum ($CaSO_4 \cdot ½H2O$) which is soft and can be easily ground to a powder called hemi hydrate gypsum plaster or plaster of Paris. If the powder is mixed with water to form a slurry or paste, it will dry and set rock hard. As the plaster-water mixture dries, water will chemically recombine with the hemi hydrate gypsum, and the material will revert back to the original composition of gypsum. While the hemi hydrate gypsum plaster is in slurry form, it can be poured between two pieces of paper and adhesive layers to make wallboard, poured into a mold, or used to fill cracks and crevices.

Synthetic gypsum is chemically manufactured gypsum and is generally a by-product that is created during various manufacturing, industrial, or chemical processes (Gypsum Association Industry, 2005). It has the identical chemical composition, $CaSO_4 \cdot 2H2O$, as natural gypsum. The suitable types of synthetic gypsum for use in gypsum board are Flue-Gas Desulphurization (FGD) gypsum, Fluoro-gypsum, Citro-gypsum, and Titan-gypsum, which are produced from the different industries. The general synthetic gypsum in North America is the FGD gypsum generated as a by-product of coal-fire electric plants. In FGD process, limestone slurry is sprayed into gas stacks to reduce sulfur dioxide. The limestone reacts with sulfur and then forms the solid gypsum at the bottom of the stack, which is then collected.

In Thailand, synthetic gypsum, a by-product from coal-fire electric plants, is not used as a raw material for gypsum board manufacturing. There is only one power plant in Thailand producing by-product gypsum, which presently creates material for other purposes. Therefore, this synthetic gypsum from one power plant does not create enough for the gypsum board demand.

Alternative materials

With the similar material

Although the mine gypsum is the primary source of the gypsum board industry, raw gypsum from nature can be replaced by synthetic gypsum. About one-fourth of current gypsum production is provided as a by-product of some industrial process. The amount of production from this kind of gypsum is increasing. It could be better with more advanced production technology.

With other materials

Many other materials are used for interior walls and ceilings besides gypsum board. The other materials used for lightweight walls are plywood, CDX plywood, veneer plywood, oriented strand board (OSB), particle board, and medium-density overlay (MDO). Each of these has special qualities but uses the same structure as gypsum board. The engineered wood products provide a good texture, and MDO has a wood-like surface. Although many lightweight products are offered, nothing can replace gypsum board for its noncombustible qualities.

Environmental effects

The gypsum mineral itself is non-toxic and can be helpful to animal, plant life, mankind, and the environment when used in soil additives, surgical and orthopedic casts, and color additives for drugs and cosmetics. So, it is not going to harm people who work in factories, on construction sites and in the buildings after construction.

New gypsum board manufacturing plants are designed to be energy efficient while existing plants have been upgraded to use energy efficiently. Some manufacturing facilities co-generate electrical power as part of their operations. Exhausted gypsum mines and quarries are rehabilitated to merge with the existing natural landscape. Gypsum waste from wallboard manufacturing processes can be recycled in-plant. The gypsum core and paper covering are separated and fed back to the raw material stream along with new material. Over 90 percent of the gypsum board paper used is from recycled material (gypsum association).

New construction and renovation also generates wallboard scrap. About 10-20 % of recycled gypsum comes from construction and renovation scrap. The new construction gypsum board scrap can be ground and used as a soil conditioner. The other potential market for these recycled products is in cement production used as a stucco additive, in sludge drying, in water treatment, in grease absorption, and for marking athletic fields (Founie, 2003). Proper disposal of waste gypsum board from demolition, renovation, and remodeling projects needs cooperation from various community sectors. When disposed of properly, waste gypsum poses no health or environmental threat. The gypsum industry is working on disposal solutions for this type of waste.

In the U.S., the gypsum industry increasingly uses ‘synthetic’ gypsum to manufacture gypsum board. This raw material is a by-product, or waste material, from other manufacturing process. By using what would otherwise be waste products, the gypsum industry reduces the stream of solid wastes going to landfills and at the same time extends natural gypsum reserves.

Recommendation for gypsum board

Gypsum board is strongly recommended because it is a very green material. It is environmentally friendly for several reasons. Gypsum board is a non-toxic, inexpensive, easy-to-install, and a lightweight material that is generally used in both lightweight walls and ceilings. It has better quality in fire-resistance, thermal-resistance, and acoustics when compared with other lightweight products. The amount of energy lost in the production process is low. The synthetic gypsum as waste from by-product processes can replace natural raw gypsum in the gypsum board industry. In this way, many manufacturers develop a better product and recover the waste to decrease environmental problems.

However, the good qualities of gypsum board do not mean it can be used any place for any task. Although the U.S. uses gypsum board everywhere, including exterior walls, using gypsum board for an exterior wall in Thai buildings is inappropriate because the paper and gypsum could not weather Thailand's humidity during the rainy season. The last thing to consider is that different kinds of gypsum boards have different qualities which mean the type must be carefully selected for different purposes.

Roof tiles

Roof tiles have been used in numerous parts of the world for a long time for covering buildings and protecting them from solar heat and rain. Roof tile materials vary depending on availability in each region. The traditional materials are clay, wood, and slate. The tiles come in various sizes and shapes depending on their structure, installation, and purpose. Some tiles, like ridge, hip, and valley tiles, are custom-made to fit exactly where the roof planes and pitches met. Tile is typically hung on the roof and arranged parallel across the surface. Top rows always overlap the row beneath it in order to let rainwater run off and to cover the nails.

Use in Thailand

In traditional Thai column-beam structure systems, loads from roof tiles, hung on battens, transfer the weight to rafters and beams. The roof material varies by region and also building types. In the past, the traditional materials for the roof were chosen depending on the purpose. Durable materials like clay tiles and wood shingles were used in the important buildings like palaces, temples, and municipal buildings while ordinary materials like leaf or bamboo were used for the temporary shelters and typical houses. These traditional materials were used because the weather in Thailand is hot and humid. They allow air ventilation through the top of the structure. Presently, many new materials have come out in the market. Unfortunately, Thai people overlook the benefit of traditional materials. They adopt new materials of high strength, state-of-the-art, and modernist style which have been changing the application of Thai materials. The materials that have been used instead of traditional ones include concrete flat slap, metal sheet, and asphalt shingle roofing.

Presently, roof tiles are widely used for residences, which is the majority of the construction in Thailand. Many kinds of tiles are available in the market, including both domestic and imported tiles. The most popular tiles are clay , ceramic, concrete, and cement.

Clay roof tiles

Clay tile roofing was introduced to Thailand over 200 years ago by Chinese merchants. It was first used only in the important places such as palaces and temples where durability was necessary. Since then, it has been widely used for common buildings and houses. Clay tile is still in high demand today although there are many roofing materials available in the market. Roof tile laying has become a symbol of Thai culture reflecting beautiful, traditional buildings. Its earthy texture and terracotta color provide a comfortable and natural feeling. Many people such as resort owners or home owners tend to use clay tile to create Thai contemporary styles even though other materials are cheaper.

In the Thai market, there are two different medium-sized clay tiles. Traditional clay tiles are flat and modern clay tiles have a curly shape. Flat clay tiles or shingle clay tiles typically come in two shapes: diamond and bird-tailed. For multiple uses and different appearances, several shapes can be provided. With the small size of clay tiles, it creates beautiful smooth curves on the roof which is a main characteristic of Thai buildings. Unlike the flat tile, the modern clay tiles are bigger and come in standard sizes. The modern clay business is monopolized by the Siam Cement Company Group.

Figure 33: Clay roof tile commonly used in the country

Physical properties

The size of the traditional clay roof tile is approximately 13-16 × 20-26 cm. With no standardized sizes, the shapes vary depending on the manufacturers. Its weight is 0.55-1.0 kg/piece and the usage is 50-75 pieces per m^2. Alternatively, the curved clay tile comes in a bigger actual standard size: 29 x 45 cm. with the 3.8 kg/piece in weight and the usage is 11 pieces per m^2.

Clay tile is very durable and has good fire resistance, similar to brick properties. The compression strength of clay tile is 160 kg/cm. It is good for buildings in hot and humid areas since heat is able to ventilate between each tile gap and in the cavity of the tile itself. Clay tile is cleaned by the rain easily and is also easy to maintain by replacing some broken pieces without changing the whole roof.

Raw materials, mines, and production line

Similar to brick, only clay from a quality clay pit is used to create a smoother, denser, and more durable material. Clay tile factories are always located near clay pits for economic reasons. The mixed clay is cast in high press machines to create thinner tiles for roofing. Then damp tiles are dried out either under the sun, or by machines. Traditional clay roof tiles come in a natural terracotta color. Modern clay tile comes in seven solid colors. Sometimes color pigments are sprayed during the drying process to make the color long-lasting, then they are fired at high temperatures to achieve the desired strength.

Ceramic roof tiles

The ceramic tile has also been used for a while as flooring materials and wall cladding. In appearance, the ceramic roof tile is similar to concrete roof tile. Since the ceramic tile prices are much higher than concrete tiles, many people prefer using concrete tile. The joint venture between Siam Cement and SACMI (Italy) is the only company in Thailand that produces the real ceramic tile for roofing.

Ceramic roof tile is considered a high quality tile in Thailand and is only used for luxury houses. It costs two to three times more than concrete roof tile. Ceramic roof tile is very similar in appearance to concrete tile and it is difficult to tell them apart at first glance.

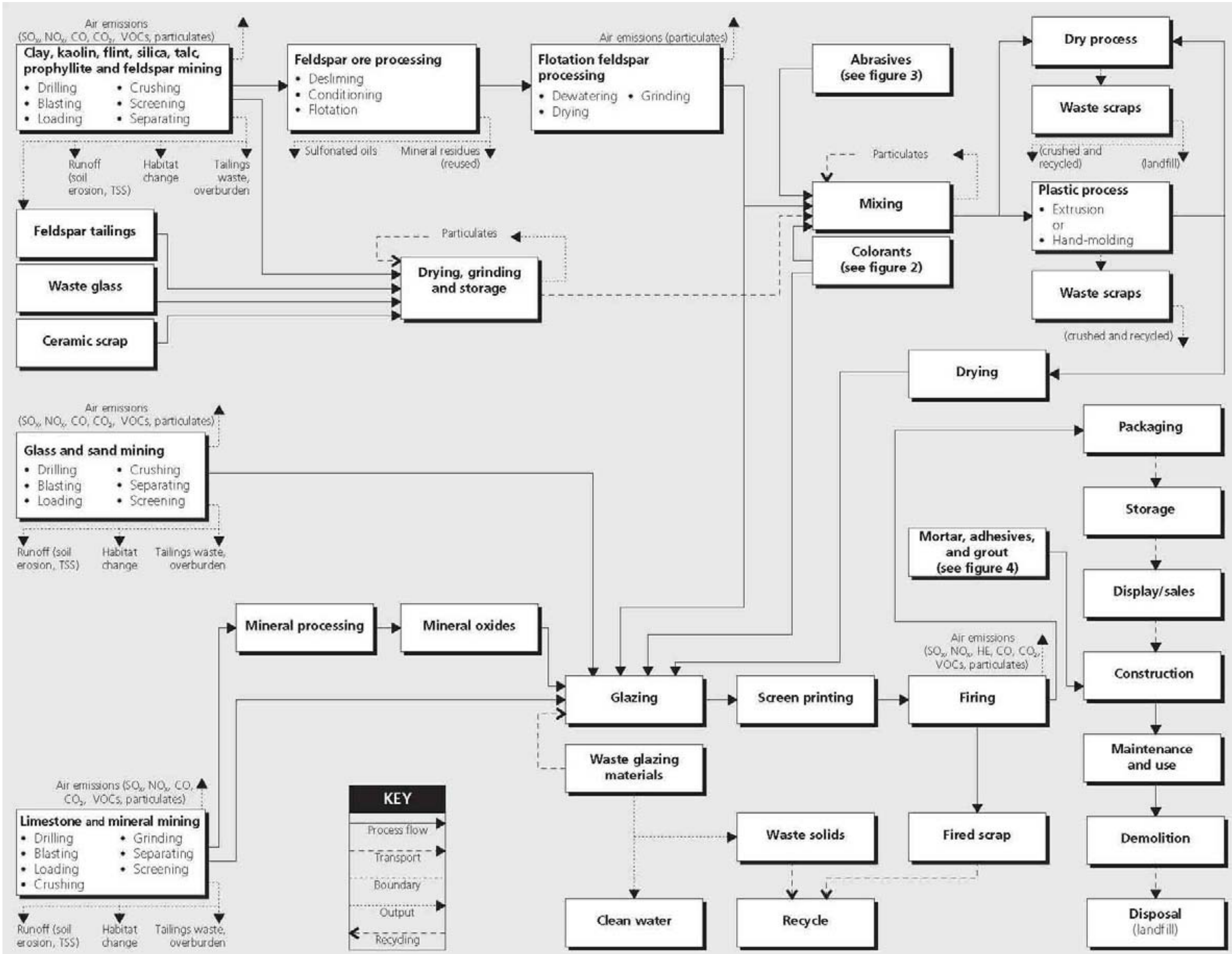

Figure 34: Life cycle of ceramic tile *(The Environmental Resources Guide, 1996)*

Figure 35: Ceramic roof tile

Physical properties

Ceramic roof tile is a very high quality product compared to other roof tiles. It is smooth with no small cavities which prevents the roof from getting dirty. It comes in the standard size of 33 × 42 cm, and weight 3.5 kg/piece with 9.8-10.4 pieces per square meter. The compression strength of ceramic tile is over 200 kg. / cm. Due to its melting point of 1,100 ˚C (590 ˚F), it is more durable than clay and concrete roof tiles. It is a good heat reflector because of its special coat, its fire resistance, and is overall better for the variable weather in Thailand. The color is smooth and does not fade even when exposed to direct sunlight. The modern ceramic roof tiles also have a dry installation technology which claims to make the roof 100% water resistant.

Raw materials, mines, and production line

Ceramic tile is made from the same high-density clay that clay roof tiles are made. The mixed clay is also pressed in a high-pressure machine. The production processes differ when the ceramic tiles are coated, dried, and before firing at 1,100 ˚C, which adds more strength and durability. It can be installed in a dry installation system unlike other tiles, which use the old-fashioned cement adhesive system. These advantages add more value to the product and increase its quality.

Concrete roof tile

Concrete tile is a well known material for roofing in Thailand. Most subdivision residents use concrete roof tiles. In the roof market, concrete tile from the Siam Cement Company gets the highest market share because of the amount of advertising, service and installation packages offered to customers. Although concrete tile appearance and ceramic tile appearance are very similar, their qualities are entirely different.

Figure 36: Concrete roof tile

Physical properties

Concrete tiles are sold in fifteen solid colors and three shapes. The compression strength of concrete tile is 150 kg/cm. Its actual size is 33 × 42 x 1.2 cm. The weight is 4.00 kg/piece and use up about 9.8 to 10.4 pieces/m^2. Concrete tiles are durable and fire resistant. Concrete roof tiles' color is longer lasting than clay tile but less than ceramic tile. These are also developed to use the same dry installation system as ceramic roof tile.

Raw materials, mines, and production line

The main raw materials in concrete tiles are cement and sand. The current technology uses a high pressure pressing process which then fires them in the heat and sprays them with pigment in an airless spray system. The water based acrylic dry paint coats the tile three times to make the color long lasting.

Environmental effects

The primary materials used to produce tiles, clay and sand, are abundant, but petroleum, natural gas, and coal are limited natural resources. Seventy to 90% of tile manufacturers in the U.S. recycle the fired scrap. In Thailand, there has been no research or reports about the environment effects or recycling plans for tile production. Waste clay in the pre-burning process is restored to the mixing process, while the broken waste after burning can only go to the land fill. Nevertheless, the durability of tiles means that tiles do not need much maintenance or replacement after construction.

The environmental effect of roof tile is similar to ceramic tile. Creating ceramic tiles, whether it is for roof, floor, or wall uses an embodied energy of about 25,161 Btus/ft^2. The energy required for firing tiles is estimated by the ceramic tile industry in the U.S. to be 18,500 Btus/ft^2. These numbers show that the burning process is the most energy consuming part of the production process. Though ceramic tile does not release any air pollution to the indoor or outdoor environment, the old fashioned installation which uses adhesive and mortar for grouting could be a source of air emission.

Figure 37: Wood shingle roof tile is very common in the Northern part of Thailand

Figure 38: Cement tile

The clay tile consumes much lesser energy than ceramic tile because it is burned at lower temperatures and is not coated. On the other hand, the energy consumed during the production of concrete tile is much higher than ceramic tile. The cement itself, which is used as a base material, consumes 2,402 to 4,060 Btus/lb excluding drying energy and tile coating. Moreover, air pollutants such as CO^2, NO^2 and SO^2 are released by the cement industry.

Recommendation for roof tiles

The roof tiles are heavily used in residential, small commercial buildings, and low-rise public buildings like temples and schools. The roofing selection is always based on buildings or owner decisions and sometimes with the help of an architect's suggestion. Cost is the major factor for middle class home owners, while aesthetics is the other main factor. The owners always want the highest quality with the cheapest price. To make a good decision, architects and home owners should know and understand the product properties, prices, labor costs and time, maintenance, and environmental effects.

According to product properties, clay tile is the most natural product with the least harm to the environment. It is good for ventilating houses not using air conditioners. Though it is very attractive as a finished product, the cost could be higher from the labor required to lay the small pieces of tile. Ceramic tile provides the best properties for modern buildings and is good for our environment. The ability to reflect heat and water offers advantages for an air conditioned home. The drawback of ceramic tile is the high price, which is the company's market strategy to reach the affluent target audience. Because of this situation, concrete tile gets a higher market share for ordinary housing due to its similar appearance. However, concrete tile is a poor material considering the environmental effect of cement. Moreover, its heavy weight costs higher prices for roof structure. However, in Thailand, since this type has good service and a ready-installation system, concrete tile is widely used with less problems and shorter time during construction.

Chapter 4

Sustainable summary

The sustainability issue is a combination of science and social concerns. To define the sustainability of a material, there are many factors to consider. Some of these are the embodied energy used in the production process and environmental effects. In addition to that, materials properties, life-cycle, recyclability, and the availability of its raw materials were also examined in the materials review. Moreover, social factors such as the geography, climate, and culture should also be taken into account. Most sustainable products are usually natural products with simple extraction and manufacturing processes and are easily renewable. Some of the high quality materials available in the market are not sustainable. In addition, a product considered sustainable in one area, may not be in another area. Therefore, it is important that sustainable products be chosen to suit the particular area where the building will be constructed.

Embodied energy summary

The embodied energy numbers provided on the embodied energy summary table are collected from The Environmental Resources Guide (1996) which is generally based on United States data. For comparison, the different units like Btus/lbs, Btus/ton, and MJ/kg are converted into the same unit which is Btus/lbs. Table 3 presents the total embodied energy of each material which is broken down into four stages: raw materials and preparation, manufacturing and fabrication, packaging and transportation, and construction which is used, and maintenance.

Table 3: Summary of embodied energy *(The Environmental Resources Guide, 1996)*

Material	compound	Embodied energy used: Raw materials and Preparation stage	Manufacturing and Fabrication stage	Packaging and Transportation stage	Construction, use, and Maintenance stage	Total
Concrete	cement	4,406 Btus/lb	4,060 Btus/lb	148 Btus/lb	282 - 643 Btus/lb	**n/a** Btus/lb
	aggregate	3197 Btus/lb	none	much on transportation *		
	sand	n/a	none	much on transportation *		
Concrete block	cement	4,406 Btus/lb	731 - 964 Btus/lb	148 Btus/lb	233 Btus/lb	**n/a** Btus/lb
	mortar/ cement	n/a	2,401 - 4,060 Btus/lb	n/a		
Light weight concrete	cement	4,406 Btus/lb	4,060 Btus/lb	little on transportation *	little	much less than concrete **
	specific mortar	n/a	n/a	n/a		
Fire clay brick	brick	much on transportation *	300 - 1700 Btus/lb	much on transportation *	much	**4,000** Btus/lb
	mortar/ cement	n/a	2,401 - 4,060 Btus/lb	n/a		
Clay roof tiles	clay	much on transportation *	n/a	n/a	n/a	similar to fire clay brick ***
Ceramic roof tiles	clay	much on transportation *	18,500 Btus/sq .ft.	much on transportation *	n/a	**25,161** Btus/sq .ft.
Concrete roof tiles	cement	4,406 Btus/lb	more than concrete ****	much on transportation *	little	similar to concrete block ***
Steel	steel	564 - 586 Btus/lb	11,000 Btus/lb	much on transportation *	n/a	**19,200** Btus/lb
Glass	glass	1,000 Btus/lb	5,400 - 6,000 Btus/lb	4,100 Btus/lb	little	**15,000** Btus/lb
Gypsum board	gypsum	1,400 Btus/lb	3,000 Btus/lb	n/a	little	**18,250** Btus/lb
	paper	15,650 Btus/lb				

* Energy used on transportation stage depends on weight of material.

** Light weight concrete uses 70 percent less amount of cement than normal concrete.

*** Clay roof tile has very similar raw materials and production process as fire clay brick. Concrete roof tile has the same raw materials as concrete block.

**** Amount of energy spent in coating stage.

The numbers provided in each stage give a general idea of the amount of energy consumed in each process, but the sums are not necessarily equal to the total embodied energy found in the last column. The reason is because one unit of the finished material is composed of more than one unit of the raw materials and data on the ratio of raw materials used to produce one finished product are not available. These numbers rely on the amount of energy required to make the initial finished material, but do not include the energy the materials consume in its lifetime.

Another source of embodied energy data is the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia's national science agency. Data from their research show that embodied energy should not only be counted during the initial production, but that the whole life cycle of the product should also be considered. Both bar charts below present the embodied energy in two different ways. The first one compares the embodied energy of each material during initial production while the second one compares the embodied energy of the material's lifetime including its reuse and recycle processes.

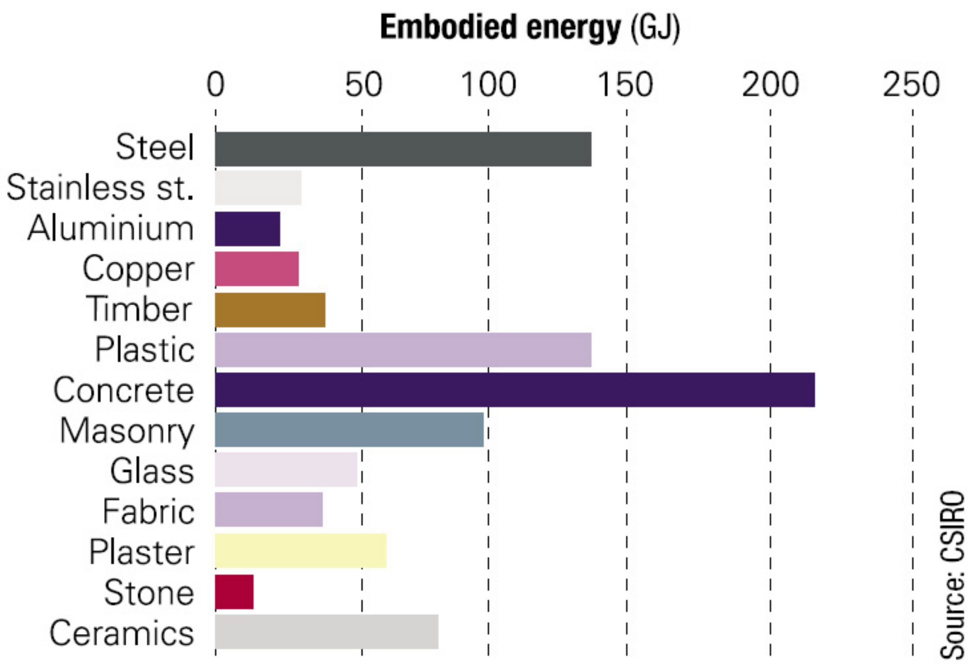

Figure 39: Embodied energy of various construction materials

Materials summary

The materials summary table presents the factors related to sustainability such as embodied energy, environmental effects and harm to user, durability, availability, and recyclability. Except for embodied energy, the literature does not provide specific statistics for the other factors. However, they do illustrate how these factors were considered in terms of the specific materials examined here. Upright and inverted triangles were used as symbols to denote the ranking of the sustainability factors. The more upright triangle symbols there are for each factor, the more sustainable the material is. Consequently, the more inverted triangle symbols there are, the less sustainable it is. The embodied energy column is a summary of table 3. The factors of Environmental effects, harm to user, durability, availability, and recyclability are summarized from the materials review. Material durability means the length of time each material can serve its normal purpose. The availability factor is concerned with the amount of raw materials in Thailand. The recyclability rank being used here utilizes information based on the US because there is no available data on materials recycling in Thailand.

The price rates are assumed from the market price in Thailand which can be adjusted following demand and supply. Same as the price, the labor skills required for each material can be improved if those materials have more demand and knowledge is provided.

Table 4: Material summary

Material	Embodied energy	Environmental effects	Harm to user	Price
Concrete	▼▼	▼▼▼▼▼	▼▼▼	▼▼▼
Reinforced concrete	▼▼▼	▼▼▼▼▼	▼▼▼	▼▼▼
Pre-cast concrete	▼▼	▼▼▼▼▼	▼▼▼	▼▼▼▼
Concrete block	▼▼	▼▼▼▼	▼▼▼	▼▼▼
Light-weight concrete block	▼▼▼	▼▼▼	▼▼	▼▼▼▼
Brick	▼▼	▼▼	▼	▼▼
Steel	▼▼▼▼	▼▼	▼	▼▼▼▼▼
Glass	▼▼	▼	▼	▼▼▼
Composite glass	▼▼▼	▼	▼	▼▼▼▼
Gypsum board	▼▼	▼▼	▼	▼▼▼
Clay tiles	▼▼	▼	▼	▼▼
Ceramic tiles	▼▼▼▼	▼▼	▼	▼▼▼▼
Concrete tiles	▼▼▼	▼▼▼▼	▼▼	▼▼▼
Bamboo	▼	▼	▼	▼

▼ very low (very good)
▼▼ low (good)
▼▼▼ normal
▼▼▼▼ high (bad)
▼▼▼▼▼ very high (very bad)

Table 5: Material summary (continued)

Material	Durability	Availability	Recyclability	Labor skills required
Concrete	▲▲▲▲	▲▲▲	▲	▲▲▲
Reinforced concrete	▲▲▲▲▲	▲▲▲	▲▲	▲▲▲
Pre-cast concrete	▲▲▲▲▲	▲▲▲	▲	▲▲▲▲
Concrete block	▲▲▲▲▲	▲▲▲	▲	▲▲▲
Light-weight concrete block	▲▲▲▲	▲▲▲	▲	▲▲
Brick	▲▲▲▲	▲▲▲▲	▲▲	▲▲▲▲
Steel	▲▲▲▲▲	▲▲	▲▲▲▲▲	▲▲▲
Glass	▲▲▲▲	▲▲▲	▲▲▲▲	▲▲▲
Composite glass	▲▲▲▲▲	▲▲▲	▲▲▲▲	▲▲▲
Gypsum board	▲▲▲▲▲	▲▲▲▲	▲▲▲▲	▲▲▲▲
Clay tiles	▲▲▲▲▲	▲▲▲▲	▲▲	▲▲▲▲
Ceramic tiles	▲▲▲▲▲	▲▲▲▲	▲▲	▲▲▲▲
Concrete tiles	▲▲▲▲	▲▲▲	▲	▲▲▲▲
Bamboo	▲▲	▲▲▲▲▲	▲▲▲	▲▲▲▲

▲▲▲▲▲ very high (very good)
▲▲▲▲ high (good)
▲▲▲ normal
▲▲ low (bad)
▲ very low (very bad)

Materials greenness

Materials greenness is characterized by the sustainability factors presented in Table 4 and 5. The following table illustrates the greenness rate (sustainability rate) of different construction materials. The results are analyzed from the other two conclusion tables which were integrated and displayed by counting the marks. The brown marks in table 4 represent the negative score while green marks in table 5 represent the positive score. The gray marks in both tables are not counted in rating the materials. The local factors involved in a specific building could possibly improve how materials are used and should be considered case by case.

The different colors and number marks in table 6 are symbols of the different ranks of green to brown for the materials. The materials with five green marks are the very green materials, which are highly recommended for use, while the one red mark stands for the very brown materials which should be avoided if possible.

Table 6: Sustainable summary – Greenness rate

Material	Greenness rates	Score
Concrete	▲	-2
Reinforce concrete	▲	-1
Pre-cast concrete	▲	-1
Concrete block	▲ ▲	0
Light-weight concrete block	▲ ▲	0
Brick	▲ ▲ ▲ ▲	4
Steel	▲ ▲ ▲ ▲	5
Glass	▲ ▲ ▲ ▲ ▲	7
Composite glass	▲ ▲ ▲ ▲ ▲	7
Gypsum board	▲ ▲ ▲ ▲ ▲	8
Clay tiles	▲ ▲ ▲ ▲	7
Ceramic tiles	▲ ▲ ▲ ▲	4
Concrete tiles	▲ ▲	-1
Bamboo	▲ ▲ ▲ ▲ ▲	7

▲ ▲ ▲ ▲ ▲	very green -- highly recommended	6 to 8
▲ ▲ ▲ ▲	green -- recommended	4 to 5
▲ ▲ ▲	normal	2 to 3
▲ ▲	brown -- not recommended	0 to 1
▲	very brown -- not recommended	-2 to-1

The concrete products including reinforced concrete, pre-cast concrete, concrete block, and concrete roof tiles are all on the brown side which shows they are far from being ideal sustainable materials. On the contrary, some other common materials in Thailand like glass, steel, gypsum board, clay tiles, and bamboo should be encouraged for their greenness. The other materials such as lightweight concrete block, brick, and ceramic roof tiles are the materials which can be considered neutral. They could possibly be green and can be even greener with appropriate usage.

Chapter 5

Recommendation

Recommendations are presented here for the utilization of sustainable construction materials for three typical types of building in Thailand. These types of building are type A: the passive comfort building, type B: the active comfort building, and type C: the mix-comfort building. These recommendations are based on the sustainability concept and the surrounding contexts which include climate, geography, and culture.

Passive comfort or Type A

Passive comfort buildings are buildings which use natural elements such as wind, solar energy, and surrounding trees to create the comfort zone inside the building. The passive comforted system is normally found in the traditional Thai building, rural buildings, and present suburban housing. Presently, people require more comfort and convenience in their lives. This contributes to air pollution and high population density in the city which decreases the comfort traditional buildings used to offer. However, this type of building is still excellent for low density areas and regions where there is little or no pollution, like suburban areas as well as the North region of Thailand where the climate is quite comfortable.

The Type A building basically has to open in the right place and is properly oriented to allow natural light and effective air ventilation into the building. The structure and materials should be lightweight and thermal mass products should be avoided especially on walls and the roof.

Sustainable materials recommended for Type A

Table 7: Sustainable materials recommended for Type A building

Assembly		Materials I *	Materials II **	Comments	Avoid
structure	column and beam	steel framing	wood	light structure is more appropriate	thermal mass structure
stairs		wood or steel structure	reinforce concrete	wood and steel stairs require skilled labor	concrete stairs if possible
wall	exterior wall	wood, vinyl composite wall	light weight concrete block	vapor retarder is recommended for composite wall	concrete wall, metal cladding
	interior wall	gypsum board	plywood	-	brick
	wall framing	wood framing	n/a	-	n/a
roof	high slope roof	clay or ceramic tiles	shingle wood tiles	wide overhanging roof is highly recommended	metal sheet or flat roof
	roof framing	steel framing	wood framing	laying clay and wood tiles require closer framing	oversize box-steel
ceiling	insulated ceiling	gypsum board	plywood	add at least one service shaft	aluminum frame
window	louver/ slide/ swing pane	glass or wood louver	plain glass	insect screen is required	fixed windows
pavement		gravel	blocks	blocks with grass are highly recommended	solid concrete pavement

* Materials I are recommended material for each part of building

** Materials II are those which are alternatives for each part of the building

Active comfort or Type B

Active comfort buildings are buildings which use electrical or mechanical equipment such as air conditioners and artificial lights to improve the comfort of the people who use the building. Buildings with the active comfort concept are usually found in closed areas with less space and fewer openings, normally located in the cities or metropolitan areas. In addition, they are mostly used in the daytime such as office buildings, department stores, convention halls, theaters, hotels, and supermarkets.

To gain the most comfort and lose the least energy, the building wall should be thick, insulated, and completely sealed. The interior environment should be separate from the exterior to keep the building cool and able to maintain the air temperature and thus maintain comfort. A good mechanical ventilation system should also be in place to generate high air-quality.

Sustainable materials recommended for Type B

Table 8: Sustainable materials recommended for Type B building

Assembly		Materials I *	Materials II **	Comments	Avoid
structure	load wall or column/beam	load bearing wall with brick	concrete column/beam	column and beam structure with thermal mass wall	n/a
stairs		brick, AAC	concrete stairs	concrete is cheaper and more available	n/a
wall	exterior wall	brick (with plaster) wall	composite wall	composite wall that includes insulation and vapor retarder	wood or other light materials
	wall cladding	insulated glass	pre-cast concrete	pre-cast concrete saves time and labor in construction	metal cladding
	interior wall	AAC	gypsum board	gypsum board wall included insulation	heavy weight materials
roof	slope roof	ceramic tiles	other tiles	wide overhanging roof is highly recommended	metal sheet or flat roof
	roof framing	steel framing	wood framing	-	oversize box-steel
ceiling	insulated ceiling	gypsum board	n/a	windows can be sealed or open	aluminum frame
opening	window	heat absorbing glass	reflective glass	should make the window open able than be sealed	wide open void
	skylight	reflective glass	insulated glass	skylight is good for the north side of building	n/a
	others	grass block	n/a	grass block is not a load bearing material	n/a
pavement		gravel	blocks	block with grass is recommended	solid concrete pavement

* Materials I are recommended material for each part of building

** Materials II are those which are alternatives for each part of the building

Mix-comfort or Type C

The mix-comfort buildings are those which use both passive and active cooling in the building. They are mostly found in the existing residential areas and subdivisions all over the country. At present, house owners in Thailand usually install a split-type air conditioning unit, especially in their bedrooms, to increase the comfort of these rooms. This is done even without making sure that windows and openings are sealed against energy loss. This lack of concern wastes energy.

Using both active and passive comfort concepts in one building is very challenging, because of the main difference which is the cooling system. It is a tough decision to decide which material or structure to use for this type of building. While the lightweight materials with good natural ventilation are suitable for buildings with the passive comfort concept, structure with good sealing is recommended for the active comfort buildings. An active comfort zone in a type C building, mainly located in a residence, is different from one in type B because it has to be protected from the sun's rays and cooled all day and night. The hot sun and moist wind during afternoon should be prevented from entering the room, especially when the air conditioner is turned on, because it will be working doubly hard and would consume more energy than normal. For the mix-comfort building, most of which are houses, the thermal mass material and heavy structure should be avoided. Although thermal mass is good to prevent the heat from entering the building during the daytime, it is going to release the heat into the building in the night time.

If an air conditioner is to be added to an existing building, heat and moisture insulation should also be added to reduce the working load of the air conditioner. On the other hand, it is much easier to consider the building design and create appropriate conditions for cooling before construction. The rooms with air conditioning should be grouped together and separated from non-air conditioned areas for easy insulation. Good orientation is also very essential to keep the active comfort zone always cool. In Thailand, where the sun passes across the Southern part, active comfort zones should be located on the North side of the building.

Sustainable materials recommended for Type C

Table 9: Sustainable materials recommended for Type C building

Assembly		Materials I *	Materials II **	Comments	Avoid
structure	column and beam	steel structure	concrete	steel structure is faster construct than concrete	thermal mass structure
stairs		wood or steel structure	concrete stairs	wood and steel stairs require skill labor	concrete stairs if possible
wall	exterior wall	wood, vinyl composite wall	AAC	insulated composite wall and AAC good for active zone	concrete wall, metal cladding
	interior wall	gypsum board	AAC	AAC good for active zone	brick for its heavy weight
	wall framing	wood framing	n/a	-	n/a
roof	high slope roof	ceramic tiles	other tiles	wide overhanging roof is highly recommended	metal sheet or flat roof
	roof framing	steel framing	wood framing	-	oversize box-steel
ceiling	insulated ceiling	gypsum board	n/a	add at least one service shaft	aluminum frame
window	louver, slide, or swing	plain glass	glass or wood louver	jalousie windows are not recommended in active comforted zone	fixed window
pavement		gravel	concrete block	concrete block with grass is highly recommended	solid concrete pavement

* Materials I are recommended material for each part of building

** Materials II are those which are alternatives for each part of the building

Chapter 6

Implementation

This dissertation focused on the analysis of the properties and sustainable factors of typical construction materials in Thailand. It also looked at the sustainable materials that are recommended for three major types of buildings, which are the passive, active, and mix comfort buildings.

A literature review was conducted to yield the data and information used in this research. The study began by looking at sustainable architecture focused on construction materials. Textbooks and websites were the major tools used to explore the meaning and background of the concept of sustainability. In addition, discussion in the classroom and term papers were also used in this research.

Regarding Thailand's sustainable materials, a review of Thai architecture and its construction materials was an essential component of the methodology. The characteristics of traditional and modern architecture were compared to help readers understand the general idea of a Thai building. This information was taken from several Thai textbooks. Then, several common construction materials used in modern Thai architecture were selected to be analyzed. These were normally fire-resistant and in the mid-range price.

The material review section presents the details of the analysis for selected materials using the factors relevant to sustainability. These factors include material properties, extent of use in Thailand, raw materials and processes, environmental effect, and recommendations. This information was mostly about Thailand which was taken from Thai textbooks, websites, online documents, and news. On the other hand, some international data like the environmental effects and life cycle of materials were referenced from the American textbook, Environmental Resource Guide. Sustainable materials were then recommended after the material status was analyzed. Then, the sustainability summary provided the analysis of the material review section. The results are presented in a format for easy comparison among the materials. Then, the sustainability or greenness rating was included in the last table, which was based on a composite of the information in the sustainability summary.

Besides the greenness analysis, the architecture recommendation part suggested several appropriate and sustainable construction materials for Thai buildings. The buildings were categorized into three types based on the cooling and comfort process. These are passive comfort, active comfort, and mix comfort. In each type, the description was provided with the recommended sustainable materials and structure for that type of building.

The research took a longer period than estimated because there were some problems encountered during the information gathering process. There might be some discrepancies in the information in the materials review section mainly because not all the factors have been measured and quantified by the literature. Collecting Thai information was very hard in some cases. There was very little research done about the sustainable issue in and for Thailand. Consequently, specific material properties, their processes, and other information had to be searched from online documents, product catalogs, and US records. The recording data, statistics, and numbers were difficult to find. The websites and online documents displayed some important information but not for all kinds of materials. Moreover, some research websites required a subscription for access to their database. Even textbooks on construction materials provided only the most basic information.

Chapter 7

Conclusion

Sustainability is the combination of many decisions that involve factors related to social, environmental, usage, quality, and construction processes. These factors had to be considered in order to achieve sustainability, which meets today's needs and can continuously provide for tomorrow's needs. It is impossible for one material or technique to be perfectly sustainable, but it is possible to be as sustainable as can be.

Although this dissertation did not conclusively decide which materials were good or bad, it did recommend the appropriate materials that should be used for each construction job. The recommendations basically put emphasis on sustainable materials. Some materials might still be recommended for their strength, availability in market, or other properties although they are essentially not sustainable.

Besides bamboo, a natural material, the greenest materials in the range are glass and gypsum board. The low embodied energy used in their production processes are an important deciding factor. They also release very little air emissions and other polluted chemicals, and both of them are recyclable. Gypsum board is very appropriate for interior walls and ceilings because it is lightweight, fire and sound resistant, and inexpensive. For glass on the other hand, using the right type of glass for the proper place and purpose is very important for sustainability.

Clay roof tile is a very green product compared to brick and ceramic roof tile, which are similar in appearance and production processes. Clay tile and brick could be produced locally and can be available at a cheap price. Using clay tile for roofing helps in building a breathable and cool structure, however, using brick for the wall may cause a big thermal mass which is not proper for some type of buildings in Thailand. Ceramic tiles for the roof are also as beneficial as clay tiles, but they can be quite expensive due to the monopoly in production.

Steel is surely a very green product for durability of structure compared with other materials like concrete. Using steel for construction reduces a lot of time and labor. Moreover, it also has high strength and can be recycled. The only one disadvantage with using steel in Thailand is the very high price, which makes steel not used to a wide extent.

Concrete and similar products such as pre-cast concrete, concrete block, and concrete roof tile are in the brown or unsustainable side. Producing cement uses up a high amount of energy and at the same time releases a lot of air and water pollution. On the positive side, pre-cast concrete is greener than regular concrete if used in big constructions. Using concrete blocks for fences and factory walls can also save in terms of time and budget. Alternatively, light weight concrete block is greener than other concrete products because it uses a lesser amount of cement. Concrete is very good for moisture and heat resistance, which is very appropriate for an active comfort zone type Thai building. Its light weight also helps reduce the structure cost.

The sustainability of using construction materials not only considers the material itself, but also other processes including the construction technique and the proper function. Overall, each of the materials, even the brown ones, can help in making buildings more sustainable if they are used wisely for the proper purpose and in the appropriate components. In the same way, sustainable or green materials, if used for the wrong purposes, could keep the building from becoming a sustainable success.

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Biographical Sketch

Pimsiri Thovichit, a graduate student in Architecture at Iowa State University, received her B.Arch. in Architecture from Chiang Mai University, Thailand in 2002. Her senior project was energy and environmental conservation in kindergarten design. She worked in architecture firms as an architect from 2002-2003. Then she worked specifically on material from 2003-2004.