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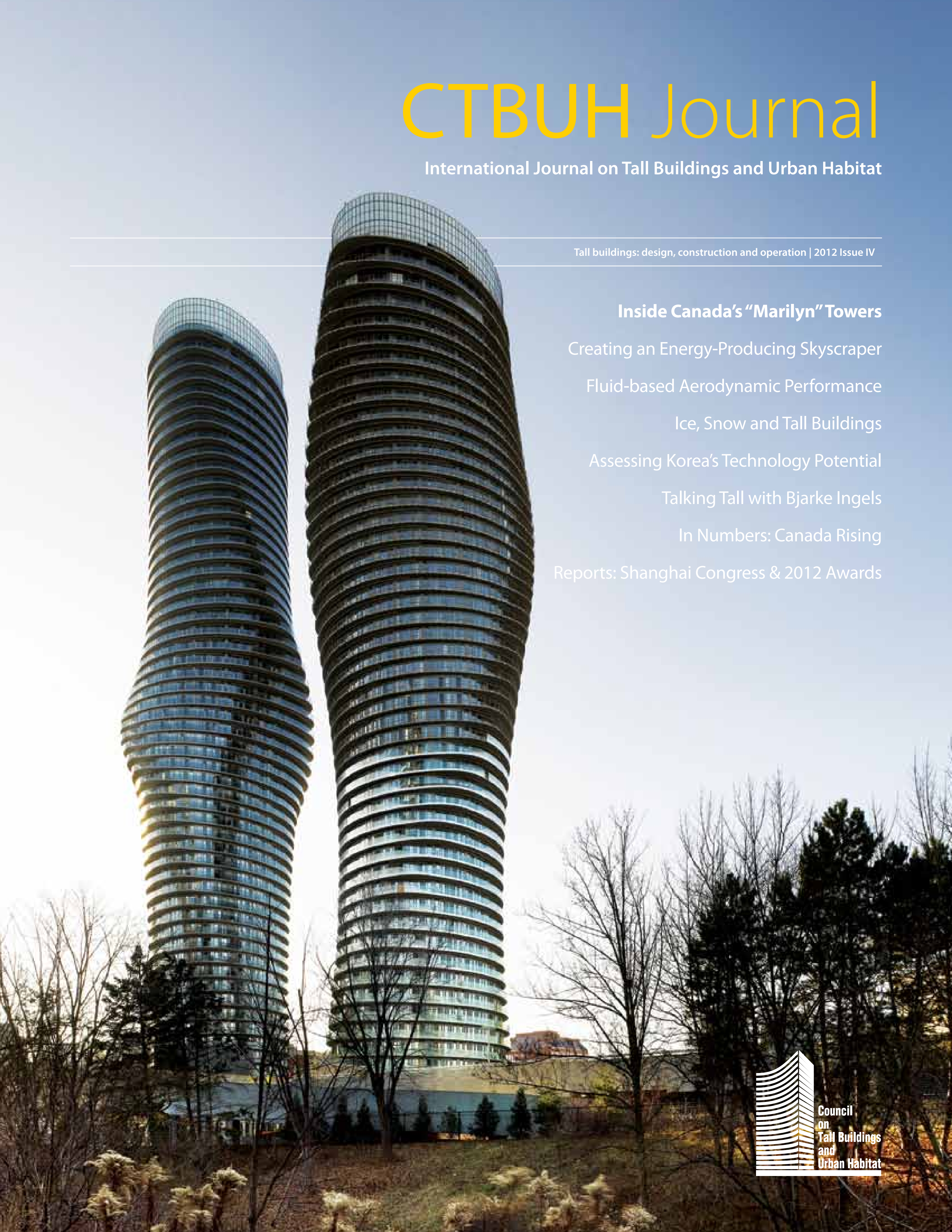

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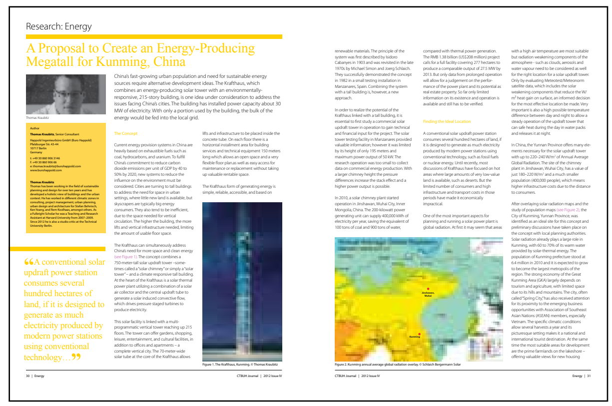

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"The challenges associated with the inherent inconsistency of air flow may open a new way of thinking about tall buildings as highly adaptive, dynamic systems capable of responding to the opportunities and challenges associated with spatially and temporally fluctuating resources."

Menicovich et al., page 18.

A Proposal to Create an Energy-Producing Megatall for Kunming, China

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> "A conventional solar updraft power station consumes several hundred hectares of land, if it is designed to generate as much electricity produced by modern power stations using conventional technology…"

China's fast-growing urban population and need for sustainable energy sources require alternative development ideas. The Krafthaus, which combines an energy-producing solar tower with an environmentally-responsive, 215-story building, is one idea under consideration to address the issues facing China's cities. The building has installed power capacity about 30 MW of electricity. With only a portion used by the building, the bulk of the energy would be fed into the local grid.

The Concept

Current energy provision systems in China are heavily based on exhaustible fuels such as coal, hydrocarbons and uranium. To fulfill China's commitment to reduce carbon dioxide emissions per unit of GDP by 40 to 50% by 2020, new systems to reduce the influence on the environment must be considered. Cities are turning to tall buildings to address the need for space in urban settings, where little new land is available, but skyscrapers are typically big energy consumers. They also tend to be inefficient, due to the space needed for vertical circulation. The higher the building, the more lifts and vertical infrastructure needed, limiting the amount of usable floor space.

The Krafthaus can simultaneously address China's need for more space and clean energy (see Figure 1). The concept combines a 750-meter-tall solar updraft tower –sometimes called a "solar chimney" or simply a "solar tower" – and a climate responsive tall building. At the heart of the Krafthaus is a solar thermal power plant utilizing a combination of a solar air collector and the central updraft tube to generate a solar induced convective flow, which drives pressure staged turbines to produce electricity.

This solar facility is linked with a multi-programmatic vertical tower reaching up 215 floors. The tower can offer gardens, shopping, leisure, entertainment and cultural facilities, in addition to offices and apartments – a complete vertical city. The 70-meter-wide solar tube at the core of the Krafthaus allows lifts and infrastructure to be placed inside the concrete tube. On each floor there is a horizontal installment area for building services and technical equipment 150 meters long which allows an open space and a very flexible floor plan as well as easy access for maintenance or replacement without taking up valuable rentable space.

The Krafthaus form of generating energy is simple, reliable, accessible, and based on

Figure 1. The Krafthaus, Kunming. © Thomas Kraubitz

renewable materials. The principle of the system was first described by Isidoro Cabanyes in 1903 and was revisited in the late 1970s by Michael Simon and Joerg Schlaich. They successfully demonstrated the concept in 1982 in a small testing installation in Manzanares, Spain. Combining the system with a tall building is, however, a new approach.

In order to realize the potential of the Krafthaus linked with a tall building, it is essential to first study a commercial solar updraft tower in operation to gain technical and financial input for the project. The solar tower testing facility in Manzanares provided valuable information; however it was limited by its height of only 195 meters and maximum power output of 50 kW. The research operation was too small to collect data on commercial energy production. With a larger chimney height the pressure differences increase the stack effect and a higher power output is possible.

In 2010, a solar chimney plant started operation in Jinshawan, Wuhai City, Inner Mongolia, China. The 200-kilowatt power generating unit can supply 400,000 kWh of electricity per year, saving the equivalent of 100 tons of coal and 900 tons of water, compared with thermal power generation. The RMB 1.38 billion (US$208 million) project calls for a full facility covering 277 hectares to produce a comparable output of 27.5 MW by 2013. But only data from prolonged operation will allow for a judgement on the performance of the power plant and its potential as real estate property. So far only limited information on its existence and operation is available and still has to be verified.

Finding the Ideal Location

A conventional solar updraft power station consumes several hundred hectares of land, if it is designed to generate as much electricity produced by modern power stations using conventional technology, such as fossil fuels or nuclear energy. Until recently, most discussions of Krafthaus have focused on hot areas where large amounts of very low-value land is available, such as deserts. But the limited number of consumers and high infrastructure and transport costs in those periods have made it economically impractical.

One of the most important aspects for planning and running a solar power plant is global radiation. At first it may seem that areas with a high air temperature are most suitable but radiation weakening components of the atmosphere – such as clouds, aerosols and water vapor need to be considered as well for the right location for a solar updraft tower. Only by evaluating Meteotest/Meteonorm satellite data, which includes the solar weakening components that reduce the W/m^2 heat gain on surface, an informed decision for the most effective location be made. Very important is also a high possible temperature difference between day and night to allow a steady operation of the updraft tower that can safe heat during the day in water packs and releases it at night.

In China, the Yunnan Province offers many elements necessary for the solar updraft tower with up to 220–240 W/m^2 of Annual Average Global Radiation. The site of the chimney plant in Jinshawan, Wuhai City, has a value of just 180–220 W/m^2 and a much smaller population (400,000 people), which means higher infrastructure costs due to the distance to consumers.

After overlaying solar radiation maps and the study of population maps (see Figure 2), the City of Kunming, Yunnan Province, was identified as an ideal site for this concept and preliminary discussions have taken place on the concept with local planning authorities. Solar radiation already plays a large role in Kunming, with 60 to 70% of its warm water provided by solar-thermal energy. The population of Kunming prefecture stood at 6.4 million in 2010 and it is expected to grow to become the largest metropolis of the region. The strong economy of the Great Kunming Area (GKA) largely depends on tourism and agriculture, with limited space due to its hills and mountains. The city, often called "Spring City," has also received attention for its proximity to the emerging business opportunities with Association of Southeast Asian Nations (ASEAN) members, especially Vietnam. The specific climatic conditions allow several harvests a year and its picturesque setting makes it a national and international tourist destination. At the same time the most suitable areas for development are the prime farmlands on the lakeshore – offering valuable views for new housing

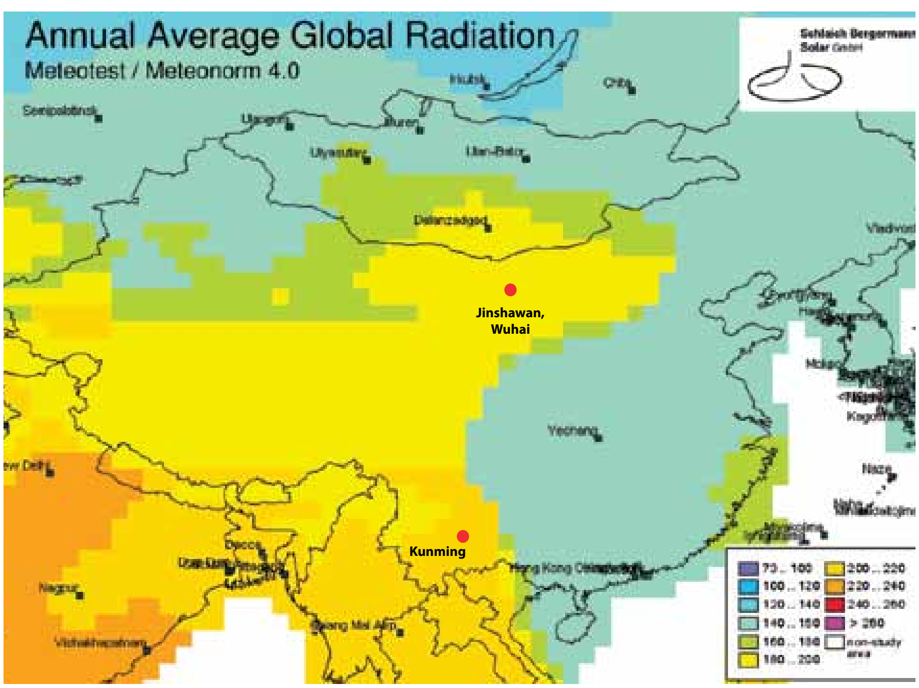

Figure 2. Kunming annual average global radiation overlay. © Schlaich Bergermann Solar

developments and an easy way to dispose wastewater.

A key element of the solar updraft tower, the collector, is already available in greenhouse structures widely used in the Kunming area. The collector is covered by ETFE foil which is produced within the mainland, allowing for a simple superstructure and easy maintenance. In order for the system to work, the collector would need a minimum diameter of 2,900 meters, which would create the world's largest greenhouse (see Figure 3). The size is needed in order to achieve electricity costs that can compete with other power plants. Covering such an area with floatglass is far too expensive and the disadvantages of transport, maintenance and superstructure made ETFE foil a much better choice, especially since much of the area already is covered by thin foil for the current greenhouses.

Underneath the foil roof warm air can rise to the tower and its turbine to generate electricity. To allow the required warm air flow, the temperature under the greenhouse slowly rises from about 20 to 60°C closer to the middle. Higher temperatures at the center make it possible to plant exotic fruits and vegetables and to increase the pallet of locally available agriculture products. The target site southeast of Kunming is already heavily farmed and the additional greenhouse space will increase productivity from the area. Black water tube bladders are placed where the temperature is highest, allowing them to be warmed during daylight hours and returning the heat at night to the structure to enable a 24-hour operation.

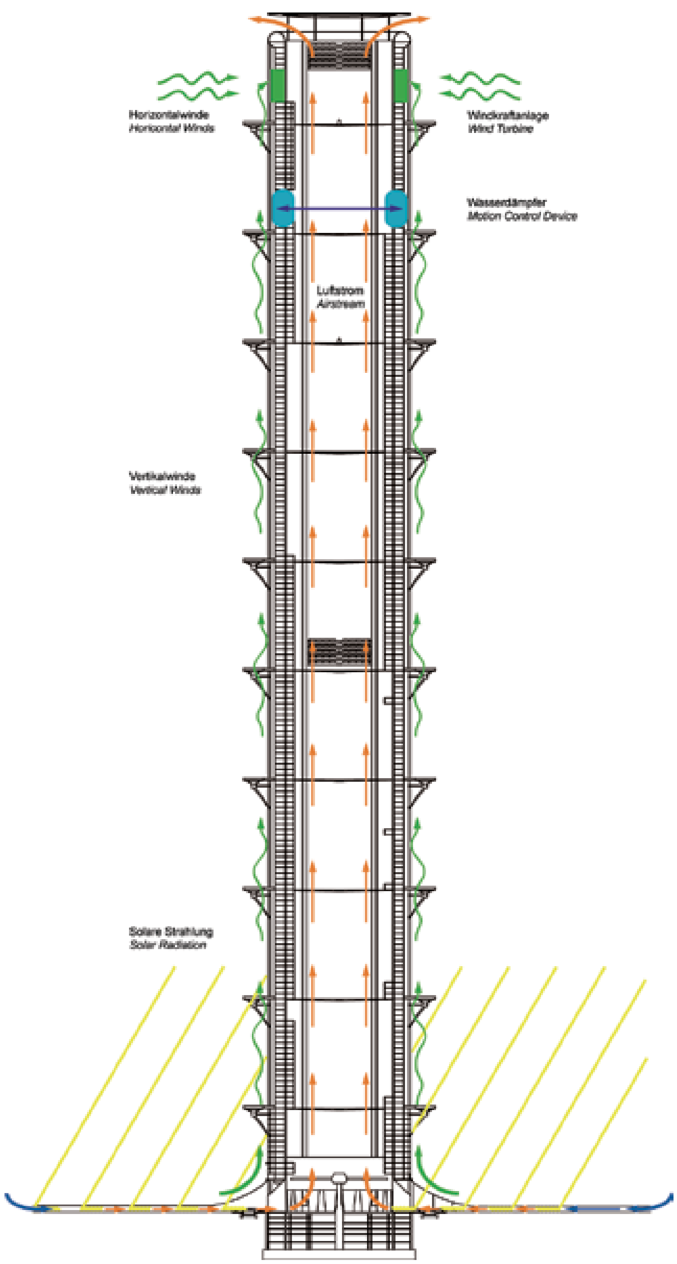

Figure 3. The Krafthaus – solar radiation principle. © Thomas Kraubitz

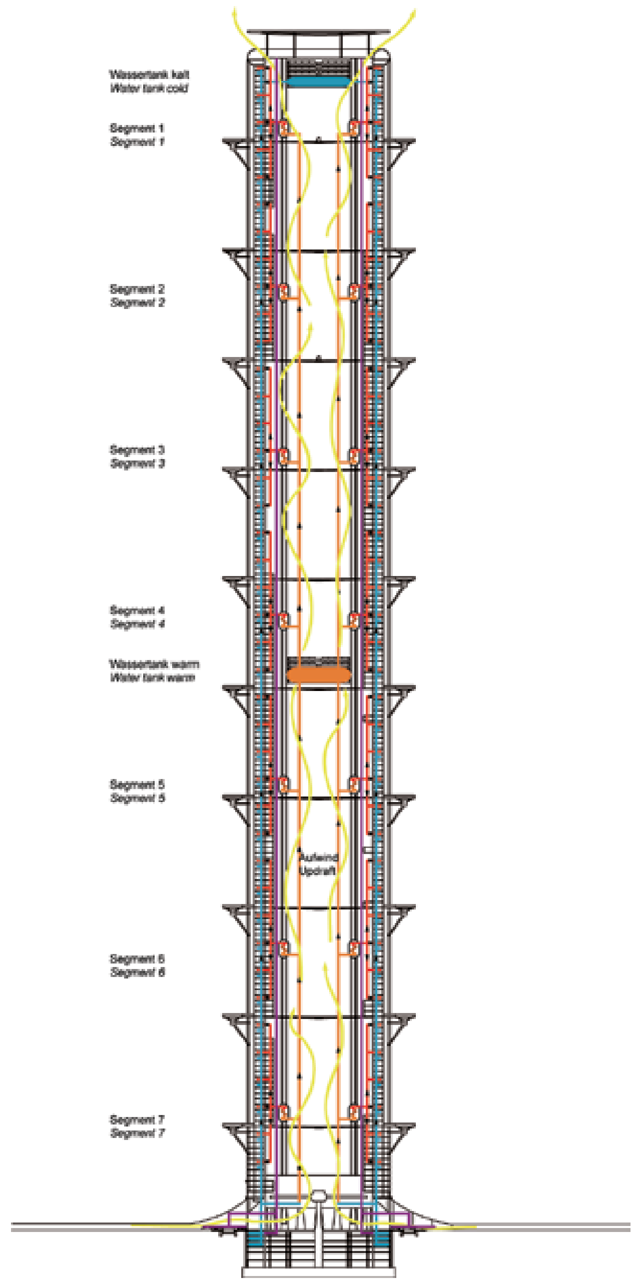

Figure 4. The Krafthaus – services distribution. © Thomas Kraubitz

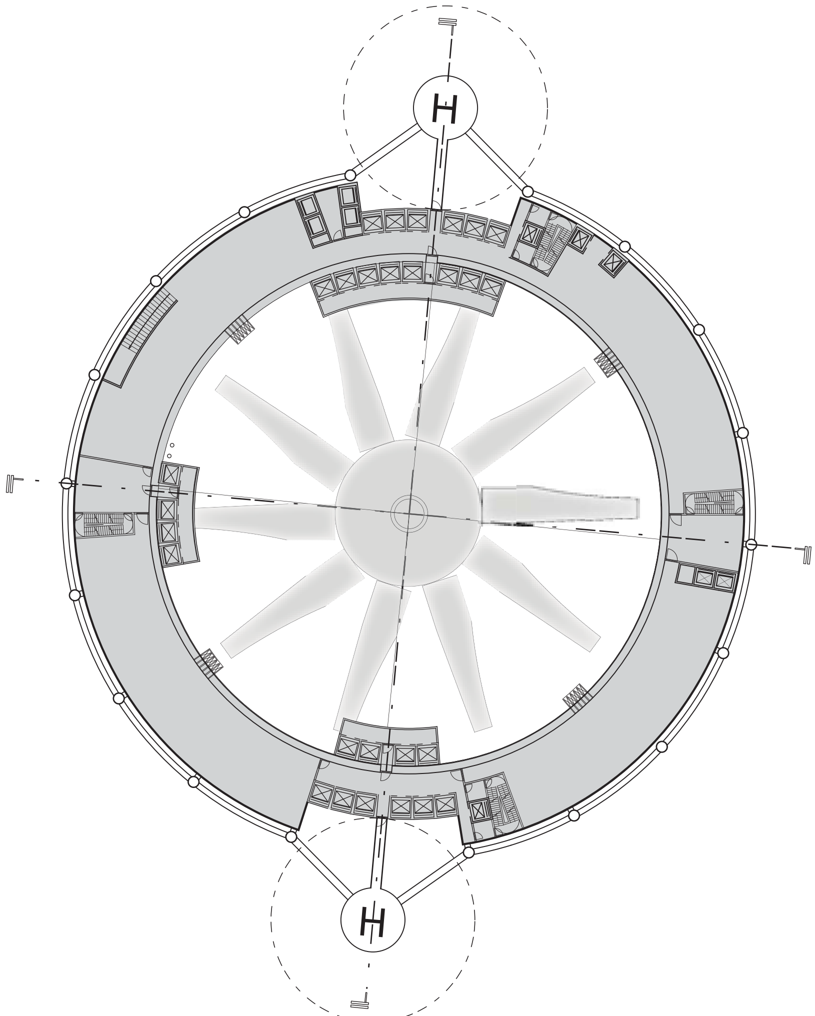

Figure 5. Krafthaus typical floor plan. © Thomas Kraubitz

> “The tower wrapped around the solar chimney leads to a novel definition of a vertical building. The occupiable building is placed like rings around the chimney, allowing a very high level of sunlight and views.”

A New Form of Vertical Building

To make high-rise buildings sustainable, adaptations from other fields need to be made. Tall structures typically become more inefficient as they go higher because of the huge amount of space required for circulation to move from the ground floors to reach the top.

The tower wrapped around the solar chimney leads to a novel definition of a vertical building (see Figure 4). The occupiable building is placed like rings around the chimney, allowing a very high level of sunlight and views. This also allows diverse layouts for each floor. With this new typology of building, the biggest part of the circulation is put inside the solar chimney, including the lifts and infrastructure (see Figure 5). All the support elements can be installed on top of the concrete walls of the chimney and maintained and updated whenever needed. The value is tremendous since each floor has the 150-meter long services and technical equipment area for any kind of installation. This approach brings great freedom in design, much larger rentable space and endless possibilities for future modifications, which is necessary for the building to be sustainable over the long term.

The rational use of energy in the Krafthaus is essential for both environmental and economic reasons, and forms a key part of the concept. The project seeks to reduce energy demand through passive measures, efficient systems, and the use of renewable energy. Demand reduction is achieved through passive measures and detailing, and specifying the correct equipment and synergetic advances to reduce the overall demand of the building. They include an intelligent use of solar gain control through orientation as well as external shading elements in the summer and the use of free heating in the winter.

The building will be connected to the main utility networks of Kunming and feed electricity produced by the Krafthaus into the grid. The operation would function as a green power provider that allows the city to reduce its CO_2 emissions further and to subsequently meet China’s commitment to reduce CO_2 emissions by 40 to 50% by 2020.

The key component of the concept is the concrete tube that needs to reach up to 750 meters to produce the required suction effect for the power plant to operate. While a number of materials have been considered for the superstructure of the Krafthaus, concrete has been found to be ideal since it is a relatively low-tech approach that could utilize local resources and labor for construction and maintenance. Concrete also allows the wall thickness to adjust from 1.8 meters at the base to 0.3 meters at the top. The floors (12 meters in depth) are placed like rings around the tube and provide additional stability and

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ample natural daylight for the building. Included are bubble decks or honey comb floor systems that also reduce the load of the floor slabs. In addition, simple water tubes in the walls or slabs allow for heating (ca. 50–55°C) in the winter. The water will be warmed by the warm updraft in the chimney, which will provide a free heating system. Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) has been considered with the cement for the tube having a net energy payback of three to four years.

Energy Efficiency

The façade is double glazed, allows ample levels of air tightness and incorporates external shading. All three of these features reduce the energy consumption of the building by lowering its cooling demand. The double glazing insulates the building from the heat of the outside air, while good air tightness prevents infiltration of hot humid air from the outside. The shading is intended to reduce the solar gains of the building. In order to ascertain the effectiveness of the external shading the building was also simulated in the IES Virtual Environment. Air tight construction and intelligently-designed shading further limits the cooling energy demand and allows for maximum levels of daylight while minimizing heat gains through the façades. Solar gain through the windows could potentially be reduced through the use of reflective coatings or films. This is combined with the use of high efficiency lighting and office equipment that reduces the electricity demand of the building.

A central energy center for the Krafthaus provides chilled water to all areas, enabling a decentralized distribution strategy while achieving high efficiency and reducing maintenance in the plant area. The cooling strategy uses a combination of air- and water-based systems to maximize efficiency and occupant comfort. Free cooling will be achieved by using the groundwater as a heat sink through the use of a closed loop heat exchanger. The feasibility of this solution will depend on the ground water conditions on the site and the local regulations on the use of ground water. It will, however, not be possible to meet the full cooling demands of the project using only ground water as a means of heat rejection. Thermal wheel heat exchangers combined with desiccant wheels will be used to create a highly efficient method to pre-cool and dehumidify fresh incoming air. Enough fresh air will be drawn in to meet the ventilation requirements of the space; the recirculated air will be passed through a standard AHU. This will minimize the energy required for cooling and dehumidification.

A mixed mode ventilation strategy utilizing both natural and mechanical ventilation modes is proposed to optimize the building’s performance by reacting to the external surroundings. The offices will use a VAV (variable air volume) system. This has the advantage of providing optimal internal air quality and is very quiet, while allowing for flexibility and personal temperature control within individual zones. In the hotel section a VRF (variable refrigerant flow) system is proposed. The plant strategy will be modular to allow maximum efficiency, matched to the demand. An intelligent building management system will control when it is energetically beneficial to utilize the mechanical ventilation mode, offering the highest efficiency and the highest internal comfort. When the external temperatures are uncomfortable and energy losses using natural ventilation are high, the mechanical ventilation is used to provide a comfortable internal environment sealed from the external environment. Whenever external temperatures and humidity levels permit, ventilation openings in the façade allow for natural ventilation, connecting the user with the external environment. Ventilation will be controlled through detectors to allow set back ventilation rates, controlled by variable motorized dampers to reduce unnecessary ventilation of unoccupied spaces.

The installation of the centralized BMS system allows the overall management and operation of the Krafthaus to be tracked, controlled and monitored. The BMS system gives centralized control to functions related to lighting, ventilation, heating, cooling and facility management. Active load management uses a coordinator within the BMS system to log the required actions and ensure that simultaneous loading of the electrical system does not occur. Metering and sub-metering allows a full audit and control of the users to be conducted. Only through measurement can the energy users and improvements be found. The logging of energy use from the BMS provides a valuable resource to enable strategies for energy use reduction and identification of high users and potential plant problems.

Photo-voltaic panels on the southern façade (approximately 15,000 square meters) are in line with the projects’ commitment to green energy and also generate electricity for the building. Several generators will be installed to provide power to sprinkler pumps, lifts and lighting operations, as well as essential power requirements, in case of an emergency. A UPS System is required for the protection of services such as telecommunications and server rooms.

Water Management

Sustainable water resource management is also a key issue for the Krafthaus. Water is an important resource in Kunming and plays a major role in both the aesthetics of the area and the well-being of the users. The ethos of a sustainable water strategy should reflect the natural environment, where conservation of resources depends on highly integrated systems. The water hierarchy thus aims to reduce the demand for potable water through the use of efficient fixtures and fittings and ensuring that the distribution design is efficient before considering the use of alternative sources for lower grade or non-potable demands. This approach ensures that the most efficient and cost effective approaches are pursued first and that the right water is used for the right purpose.

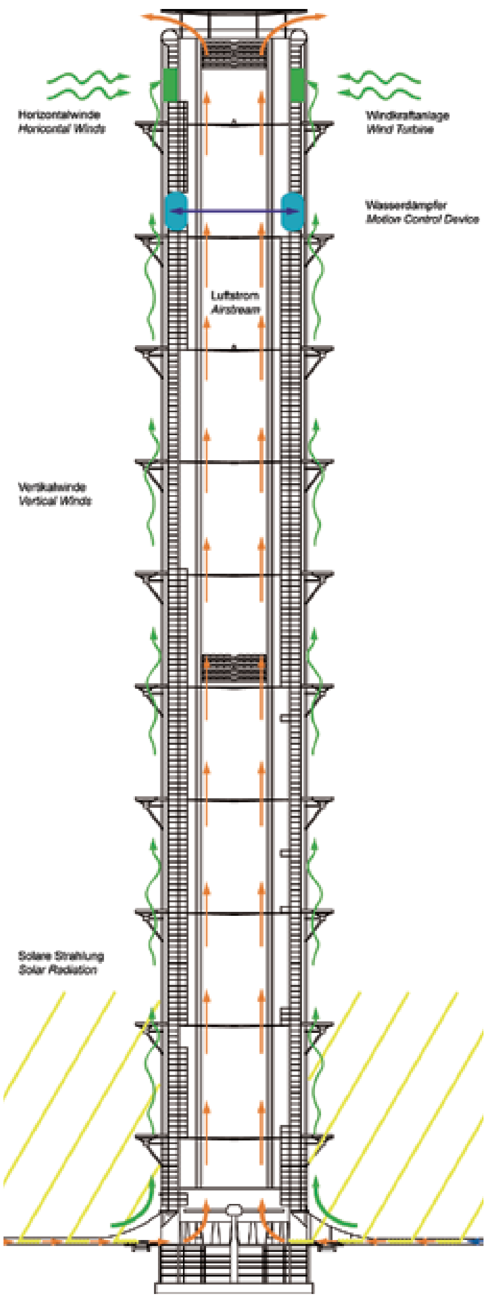

Figure 6. The Krafthaus – water distribution. © Thomas Kraubitz

A number of passive measures can be employed to reduce water demand (see Figure 6). These require no behavior change by the user, and tend to be very cost effective, using such elements as fixtures and fittings. A good practice water distribution system design, while less visible to users, can also reduce water use. The domestic hot water (DHW) will be pre-heated using the waste heat from the chimney (50°C) before being heated to the required temperature, using high efficiency gas-fired calorifiers. One goal is to reduce the overall demand and pressure on the potable water connection. A rainwater harvesting system is planned to collect rainwater for irrigation. This has the added benefit of reducing rain water runoff into the local sewer. In addition, water tanks between the 181st and 188th Floors help to stabilize the building during natural disasters (the Motion Control System) while also functioning as a water tower.

All wastewater from the Krafthaus is recycled on site and the solid waste is used as fertilizer is used in agriculture production. The water is treated through natural organisms in the roots of the plants, providing an energy-efficient means of grey water treatment, which will turn the effluent water back to drinking water and the sludge will be used as fertilizer on site.

Economic Considerations

The Krafthaus requires a large initial capital outlay, but would have relatively low operating costs. The initial capital required is roughly the same as next-generation nuclear plants. Like other renewable power sources there would be no cost for fuel, and due to the location and its continuous use for agriculture there would be no costs for the land. The less than 5,000-square meter site for the tower would be rented for a period of 99 years. The costs per kWh of energy are largely determined by interest rates and years of operation, which should be considered for at least 100 years. The concept is expected to have less of a requirement for standby capacity from traditional energy sources than wind power, since thermal storage mechanisms – the water bladders in the center – are incorporated to smooth out power yields over the day/night cycle.

Until reliable electricity cost figures are available for a time period on a utility-scale power plant size, predictions on the levelized electricity cost (LEC) are in the range of 11 Euro cents (Sclaich et al. 2005) but have to be verified by a facility in operation, such as the Jinshawan tower. The solar updraft tower can't currently compete with the LEC of approximately 5 Euro cents per kWh for a wind or natural gas plant of comparable size (30 MW), creating a high risk for the developer building a combination of a supertall skyscraper and power plant. But the income from running an observation deck and selling off units in Asia's tallest building has to be considered and could lower the LEC and reduce the investment payback time of the Krafthaus.

Conclusion

China's need for sustainable green energy sources combined with its history of agriculture and interest in developing tall buildings make it an ideal setting for the Krafthaus. Given the right environment, a 750-meter solar tower can help generate 30 MW of energy for the local community, as well as creating a self-sustaining vertical city with residential, office, retail and recreational space. More study is needed, but the concept offers a variety of benefits for China's growing urban areas. ■

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