Solar Heating and Cooling in hot and humid climates – sol.e.h.² Project Introduction

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Abstract

Energy saving in buildings is important to modern urbanization and especially challenging under the hot and humid climatic conditions of Guangdong (P. R. China). Minimized energy demand for heating (domestic hot water), ventilation and air conditioning (HVAC) in buildings is a major premise for the implementation of solar HVAC systems. The nearly zero energy building concept and solar HVAC complement each other well and are under investigations in the Austrian-Chinese research project sol.e.h.².

The implementation of an optimized building (Passive House) and solar cooling supported HVAC lead to a joint integral solution far beyond state of the art. Innovative applications of solar cooling components and new building integration methods for this very specific climate in Guangdong region are the core of this project. The joint integral system will further be developed under appropriate innovative business models.

This paper introduces the current status of buildings and solar cooling in China and presents the project idea and its methodology used to develop a solar driven nearly zero energy building in the course of sol.e.h.² project.

Keywords: Hot and humid climate, nearly zero energy building, solar cooling, integral solution

1. Introduction

China has achieved great progress in social urbanization during the last decades. The urban population has increased from 962.6 million to 1390.0 million from 1978 to 2017, while living space per capita has risen from 5.7 m^2 to 39.0 m^2 from 1956 to 2018 (CHN stat, 2019). China is building more new dwellings than any other country in the world. During the next 10 years, Chinese cities – especially economically fast-growing regions like Guangdong – are expected to provide living space for nearly 200 million people. The building construction volume is very large in China and the buildings consume around 30% of total energy of the whole society. It is estimated that this ratio will continue to rise in the future (BERC, 2019). Therefore, it is very important for China to figure out a development scheme to cut the energy use in buildings.

China has completed its '30-50-65' energy saving plan (Xu, 2015). Now it is trying to move forward towards greater achievements in building energy saving. Nearly zero energy building (nZEB – also called 'passive super-low energy building') is chosen as the next stage goal. China government has initiated a process to develop and promote nZEB in the whole country.

In 2010, the first nZEB project in China named 'Zai Shui Yi Fang' was accomplished in Qinghuangdao, Hebei Province, including several residential buildings. There have been other dozens of nZEB projects since then. These nZEB projects bring lots of valuable knowledge to the researchers and building industry. It is shown that the application of nZEB in China can significantly improve the living conditions and reduce the energy consumption. It is found that the nZEB building is economical viable. The incremental cost of nZEB is around 1,500–2,000 RMB/m^2 (cold climate) and the static payback period is about 20 years (Zhang, 2015), whereas for long-term investments the present value method should be used to express the economic impact.

nZEB is taken as a newly promoted goal and guidance for building design, construction and operation in China. Though at present there are no national standards of nZEB, some related policies have been released. Now more than 10 provinces have published policies related to promote nZEB development, including Henan, Hebei,

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Shandong, Hubei, Fujian, Shaanxi, etc. China's Academy of Building Research (CABR) has published a standard for nZEB recently (GBT 51350, 2019). It is indicated that China is making progress towards developing the guidelines for nZEB at its own pace.

Although there is a trend towards nZEB and there is a strong effort to reduce energy demands for heating and cooling there has been a tremendous increase in the market for air-conditioning worldwide, especially in developing countries. Global sales of room air-conditioners has increased dramatically; from about 44 million units/a worldwide in 2002 to more than 100 million units/a in 2013 (JARN 2015).

In 2016, air-conditioning accounted for nearly 20% of the total electricity demand in buildings worldwide and is growing faster than any other energy consumption in buildings (OECD/IEA, 2018). The People's Republic of China had the fastest growth in space cooling energy consumption worldwide in the last two decades (IEA 2019). The main reasons for the growth rate are rising living standards related to economic and population development. If measures are not taken to counteract this increase, the space cooling demand will almost triple by 2050. Beside the efficiency of chillers and load reduction in buildings and processes, solar and renewable driven cooling systems play a critical role in reducing environmental impact.

The increasing demand for refrigeration and air conditioning has led to a dramatic increase in peak electricity demand in many countries. With the increase in demand comes the increase in the cost of electricity and summer brownouts, which have been attributed to the large number of conventional air conditioning systems running on electricity. As the number of traditional vapor compression chillers grow so do greenhouse gas emissions, both from direct leakage of high GWP refrigerant, such as HFCs, and from indirect emissions related to fossil fuel derived electricity consumption.

In order to limit the negative impact on energy consumption, greenhouse gas emissions and electricity network infrastructure, solar air-conditioning is proposed as an environmentally sound alternative to conventional fossil fuel-based air-conditioning. Solar technologies are promising for a sustainable heat and cold supply (HVAC).

Solar air-conditioning is intuitively a good combination, because the demand for air-conditioning correlates quite well with the availability of the sun. The hotter and sunnier the day, the more air-conditioning is required. Interest in solar air-conditioning has grown steadily over the last 10 years. A survey has estimated the number of worldwide installations at nearly 1,200 systems (Mugnier and Jakob, 2015). Solar air-conditioning can be achieved by either driving a vapor compression air-conditioner with electricity produced by solar photovoltaic cells or by driving a thermal chiller with solar thermal heat. Several studies in the past years show the competitiveness of solar thermal and PV driven systems. Depending on the boundary condition each system configuration shows appropriate advantages. Existing simplifying studies Streicher (2010), but also more detailed studies (e.g. Henning (2010), Eicker (2012), Wiemken et al. (2013), Neyer et al. (2016), etc.) are evaluating both technologies under different boundary conditions.

The results of these studies depend on climatic conditions (ambient temperature, irradiation) as well as on the type of application (domestic hot water, space cooling, etc.), size and operation hours of the system, etc. Furthermore, they show that reasonable system configurations (base or peak load design) and different control strategies have a crucial impact on reachable non-renewable primary energy savings. Even under various economic considerations the results can differ significantly. But in general, in common controversy PV driven systems get more positive remarks for small capacity systems and solar thermal driven systems more for larger scale systems. Often quoted arguments are regarding efficiency, costs and handling of surplus energy.

The Chinese investigation in solar cooling is showing an enormous variation of different components and technologies. (e.g. different chillers (n-stage), solar thermal and PV driven systems, open and closed cycles, etc.). There are some demonstration projects of solar cooling in China, roughly 60 (Dai 2017) are in the state of field performance tests. Only little information is available of their technical and economic field performance, e.g. Jinan Disaster Prevention Centre (by Yazaki), Shanghai Electric C. (by Prof Dai) etc. One of the examples is located in Guangdong province. Several technical solutions (different chillers, desiccant cooling, solar thermal & PV driven chillers) are available and have been tested in several cases.

According to the IEA's Technology Roadmap on Solar Heating and Cooling, solar cooling should cover at least 17% of the total cooling needs by 2050 (Frankl, 2012). However, in the last 10 years the development has not been as fast and effective as it was expected to be. In only a few specific cases solar cooling is economically competitive and has market appeal. The biggest challenge of the still small solar cooling market is the reduction of system costs. The standard way to reach this target besides scaling up market volumes is standardization.

A huge market segment can be seen in buildings with several thousands to several ten thousand m^2 area for residential but also public buildings. Assuming 15 W/m^2 for sensible cooling and 15 W/m^2 for dehumidification max cooling loads range between 50 and 500 kW. A reasonable medium scale range but difficult to standardize.

In common ways HVAC systems are sold once to the investor or the building promoter. The operating company is often not involved in the system selection process. Main decisions are taken on initial investment or on return on investment. For both, nZEB and solar thermal cooling, life cycle cost analyses make more sense. The overall economic benefit can convince more potential players.

Alternative ways of business models are coming up slowly. One of these models is an energy service company (ESCO). In some large-scale plants (>1.5 MW) the company S.O.L.I.D has successfully implemented solar thermal cooling (Feierl 2018). This denotes that the solar thermal cooling is paying off its investment and is economical feasible.

First examples in Germany are coming up with energy flat rate models including heating, cooling, ventilation and electricity. This is more suitable if the energy demands are reduced to that of a nearly zero energy building and the possibility of forecasting the demands very precisely (Leukefeld 2017). If nearly zero energy is misinterpreted, and focus is on energy production only (instead of reduction of energy demands first) these models cannot work.

There are some demonstration plants for nearly zero energy buildings and solar thermal cooling located around the world and also in China. Nevertheless, for both technologies the Guangdong climatic conditions are challenging, and many uncertainties are coming up when dealing with the concepts and integration of the innovative ideas below.

2. Project methodology

The emphasis of this project – solar HVAC and passive solutions directing to high energy efficient buildings in hot and humid climates of Guangdong – targets on the joint integral solution of building, HVAC and renewable energy leading to (primary-)energy- and cost-efficient solutions for the climatic conditions of Guangdong. In conventional ways building and HVAC is often treated separately and there are different definitions and key words directing to misunderstandings.

For the moment solar thermal cooling (and heating) seems to be out of economics and far underestimated from technical point of view. Against both technologies, solar cooling and passive houses as base for nZEB, restrictions concerning applicability and suitability are discussed controversially around the globe and besides in Guangdong. The specific hot and humid climate of Guangdong is rather challenging. But this project targets to show that with a consequent and climate specific Passive House Concept complemented by solar cooling a joint integral solution far beyond state of the art can be reached. A solar direct cooling and dehumidification without storages using the thermal inertia of the building and running the thermal chiller as heat pump for domestic hot water in parallel should allow a solar solution without any backup.

The systematic development of construction components for the envelope by means of simulations is needed. Within the optimized construction the solar cooling system will be integrated in a novel and innovative way by actively usage of thermal mass of the buildings. The HVAC solution can be simplified consequently by reducing components and adopting the operation mode of the main components. The thermal driven chiller is operating to deliver the energy demand for chilled water and providing domestic hot water at once. In this case high solar fractions are economic viable. Finally, new business models will be established, and the joint integral solution will be assessed and benchmarked against other renewable technologies extensively.

The elaboration of the joint integral building & solar cooling solution is supported by means of coupled building and HVAC simulations and laboratory measurements. The study includes various system boundary variations to identify crucial aspects for implementing the concept. A thermal driven chiller will be adapted accordingly and will be run under Hardware-in-the-Loop measurements to show the feasibility from HVAC & solar cooling side. Experiments with a functional system in a real environment complement the findings. Assessment and benchmarking are done by IEA SHC Task 53 tool and represent the base to act out different business models.

The project is organized in four work packages, aiming to organize the project in a smart and logical way. The following flow sheet is showing the interaction of each work package (WP) and their main content with headlines.

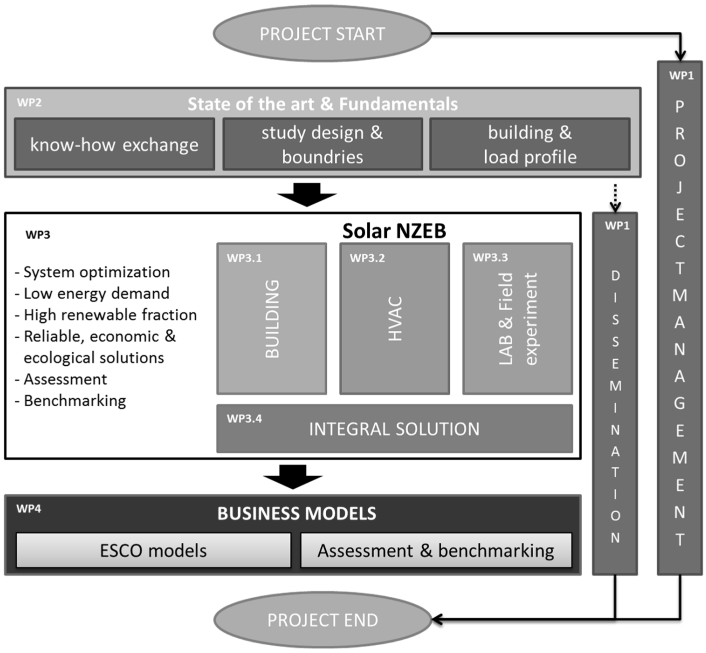

Fig. 1: Structure of the cooperative research project

WP2 is planned to be an intensive know how exchanges for all project partners. The Chinese and Austrian state of the art will be discussed and are focusing in passive house components, HVAC solutions (domestic hot water, sensible cooling and dehumidification), solar (PV + solar thermal), etc… The collection of local boundary data (e.g. climate, standards, cultural aspects, energy prices, invest costs, etc.) and the details of the simulation study will be discussed.

In preparation of the integral Building & HVAC solution the content of WP3 are the detailed definition and the elaboration of the building simulation model (construction, windows, internal gains, lighting, etc.). The work package contains the building simulations itself but also the optimization (techno/ economic) and therefore a wide range of parameter variations.

A simplified study of optimization potential for systems based on solar components (thermal driven chiller, the solar collector, PV, etc.) will be elaborated first to indicate future technology developments. After first preliminary results the HVAC design will be started. The solar cooling solutions will be designed by means of simulations, including modelling and parameter variation. The results are serving as base for the joint integral Building & HVAC solution.

In preparation of the functional systems experiments, Hardware-in-the-Loop tests of an adapted chiller shall be performed. The laboratory experiments target on real time performance testing (only chiller in lab, other components/building are simulated) under the innovative design ideas (e.g. domestic hot water and cooling in parallel, etc.) and the specific boundary conditions of the Guangdong climate and the chosen profile.

The selected building for the functional systems field test and its HVAC layout will be adopted to integrate the solar cooling solution. The detailed planning of functional systems experiment is including the solar cooling system and its components but also comprehensive monitoring equipment. The experiment will include implementation, monitoring (>6 months) and optimization. The technical feasibility and quality will be shown by processing and analyzing the recorded data.

Based on the results of building and HVAC simulations the assembling of 2 joint integral Building & HVAC solutions will be aligned. This includes the combination of building and HVAC design and their optimization. It should be shown, that energy efficiency is the basis for solar cooling systems and that Passive Houses complement such systems well. But also, a technical, ecological and economic assessment and the benchmarking of the solutions against each other and against state of the art.

Finally, in WP4, energy service company (ESCO) models will be analysed and further development of the concept for the specific boundary of a nZEB and solar HVAC (e.g. energy flat rate, etc.) will be elaborated. The adaptation of a technical and economic assessment tool (T53E4-Tool) and a comprehensive sensitivity analysis on economic boundaries for solar solutions should lead to a good base for benchmarking.

The project has started already, three buildings (with hostel, office, residential profiles) in the climates of Guangzhou where discussed. One project (small scale, 500m² office building) was selected to be optimized and realized in the course of the project. The building(s) were optimized from technical point of view. The energy demand for cooling and dehumidification is reduced by 70% compared to Chinese building standard using passive house components and principles.

Among the optimized parameters were the quality of windows (g-value), reflection coefficient of opaque walls, equivalent air-change rate (including heat/humidity recovery measures), airtightness, insulation of roof and walls and others. The results show that from the standard building to a Passive House an improvement of loads from 70 to 15 W/m² (sensible & latent) and a decrease in energy demand from 170 to 40 kWh/(m²a) (sensible & latent) can be reached in these examples.

An economic analysis of this result as well as the design and optimization of the solar cooling system and the integration in the HVAC system will be carried out in the next step. These results will be published as soon as they are available.

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