Energy Efficiency by Means of Architecture and Engineering: The Bavarian State Collection of Zoology

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Abstract

The Zoologische Staatssammlung München (ZSM) is one of the major German research institutions for zoological systematics. ZSM with over 20 million zoological objects, is one of the largest zoological collections in the world. The main aims of the institute are to save and protect the zoological objects and the enormous biological information associated with them, and to make this information available to the scientific and general public.

ZSM is housed in a building which was finished in 1985. This building was designed for good storage of the collection. We show how ZSM with its special features uses energy in a way that is as far as possible eco-friendly and economical. We want to give this as an example of an energy-saving building in its social context.

The building is very low and there are two floors, one floor slightly below the surface, the other below this. The central power station was finished in 2006 and is equipped with a facility for cogeneration to simultaneously generate both electricity and useful heat, heating pumps and a computerized central control system. An important feature is the possibility to use groundwater for heating and cooling.

Keywords: energy saving, green energy, cogeneration both electricity and heat, natural history collection

In this paper we want to introduce the building of the Bavarian State Collection of Zoology (Zoologische Staatssammlung München, ZSM)[4] with its special features which help to use energy in a way that is as far as possible eco-friendly and economical. We want to give this as an example of an energy-saving building in its social context.

ZSM is one of the major German research institutions for zoological systematics. With

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[4] Within this text the Bavarian State Collection of Zoology (Zoologische Staatssammlung München), is called ZSM even though the name differed in the past.

over 20 million zoological objects, ZSM is one of the largest and most historical zoological collections in the world. Many of these specimens have been collected by the staff and other collectors during the 200 years long history of ZSM. The main aims of the institute are to save and protect the zoological objects and the enormous biological information associated with them, and to make this information available to the scientific and general public. The science conducted at ZSM involves research on the taxonomy, phylogeny, and natural history of animals, and the institute provides a suitable and sustainable depository for zoological specimens (Liu, 2008).

ZSM is not a public museum, but organizes exhibitions in its corridors, public talks, meetings of scientists, and provides guided tours especially for groups of students and pupils, and thus contributes to public education (Liu, 2008, 2009). Furthermore, several of the scientists of ZSM contribute to zoology and biodiversity teaching at Ludwigs-Maximilians-Universität. The director of ZSM personally occupies the chair of Zoology at the university. Thus, although ZSM is not part of the university, it has close cooperation in such things as teaching students for Bachelor, Master and Doctoral theses.

History of ZSM

The roots of ZSM go back to 1759, when Maximilian III Josef, Elector of Bavaria (1727 - 1777) founded an academy of science which was obliged to collect natural objects. In 1807 this academy was reformed and in 1811 the young zoologist Johann Baptist Spix (1781 - 1826) was appointed by king Maximilian I Josef of Bavaria (1756 - 1825, the first king of Bavaria) to be responsible for the zoological collection. This is generally considered as the beginning of ZSM as a Bavarian institution. Johann Baptist Spix (later: J. B. Ritter von Spix) made a famous expedition to Brazil (1817 - 1820) together with the botanist Carl Friedrich Martius (1794 - 1868). They brought a large collection of Brazilian material which is now housed in ZSM and in the Bavarian State Collection of Botany and the Munich State Museum of Ethnology (Fittkau, 1992).

Originally, ZSM was housed in a building called Wilhelminum in the centre of Munich, together with a public museum and later the zoological institute of the university. This building was destroyed in the second world war (Kraft & Huber, 1982). Fortunately most of the specimens survived the war because they were deposited in safe places outside the city like mining tunnels. Later, ZSM found temporary accommodation in a wing of Castle Nymphenburg until the new actual building somewhat outside the city was finished in 1985.

Architectural Principles

The new building of ZSM was built from 1981 to 1985. Priority in the architectural design was the good storage of the collection which has in the meanwhile grown to twenty millions of specimens and which is of enormous value (e.g. Suarez & Tsutsi, 2004). The building is very low, there are two floors, one floor slightly below the surface, the other below this (figures 1 and 4). Only the lecture room extends over the surface (figure 5). A large block would not have been appropriate when there are surrounding small residential houses (figure 3).

The working-rooms are grouped around two open circles (figure 2) with windows and natural light, but without air conditioning. The storage rooms are next to the working rooms, without normal windows, but with air-conditioning and an alarm system (figure 2). There are 23 storage rooms (one of which is the library, and one extends over both storeys)

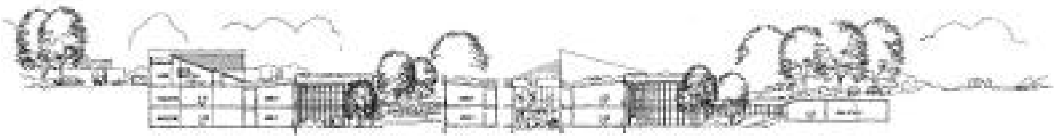


Figure 1. The side view plan of ZSM.

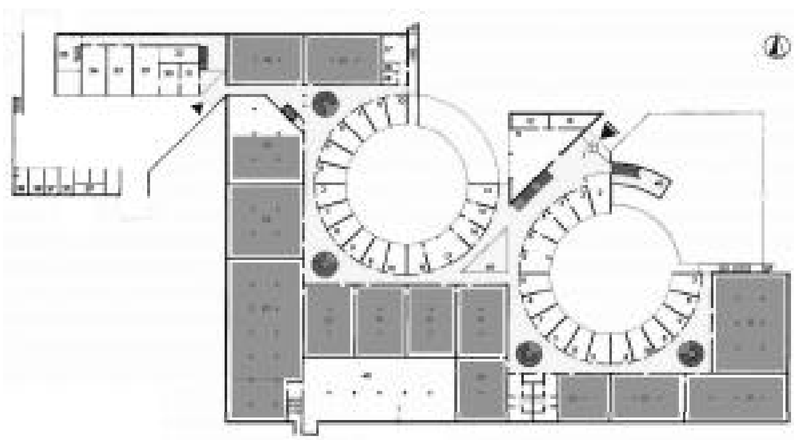


Figure 2. The first floor plan of ZSM. Storage rooms marked in grey, the arrow points out the main entrance.

Figure 3. Aerial view of ZSM and surrounding houses. The X show where the underground water is pumped up and back (photo: Erwin Lehmann).

providing altogether 5,100 m^2. The different storage rooms have different requirements for temperature and humidity depending on whether they contain, for example, dry insects, bones and furs or alcohol vials. Furthermore there are altogether 70 rooms for scientists, technicians, laboratories, workshops and so on. Thus the whole area available for use is about 11,000 m^2 (Fechter, 1992; Ruthensteiner, 1999).

For working efficiently, the working rooms and the corresponding storage rooms are next to each other. The central facilities (administration, laboratories etc.) are at the crossing centre of the two circles and near the main entrance (figures 2, 4 and 6) (Ruthensteiner, 1999).

Although there is a much colder climate in Germany than Taiwan, many buildings need more energy for cooling in summer than for heating in winter. The more or less subterranean building of ZSM saves much energy as compared to a "normal" building above ground; also most of the roof is covered by earth with grass. The whole construction benefits from the

Figure 4. Main entrance of ZSM downward to underground (photo: M. Müller, in wintertime).

Figure 5. Roof of ZSM in summer showing triangular top of lecture hall.

Figure 6. View over one of the two circular courtyards, at the lower right the library; behind the triangular top of lecture hall and solar panels.

heat capacity of the surrounding earth throughout the year. The ZSM building is quite well-known in German architecture (e.g. Grub, 1990).

When ZSM was planned and built (1978 to 1985), it was already a time of increasing prices for energy; thus a gas heat pump was installed to save energy. At that time this was still a rather new technique in Germany and this system had lots of problems in operation and maintenance. After several changes and upgrading a completely new system was installed in 2005/2006. Nevertheless we had already from that time a groundwater resource for use. We can pump up water from a depth of about 10 m at one end of the ground, use this for heating or cooling, and pump it back to the same underground level at the other end of the ground (ca. 200m distance). Furthermore the heating system was built to be used at low system temperatures, for which a heat pump is very suitable.

Of course, it is nowadays possible to design and construct new museum buildings with modern energy-saving architecture which need considerably less energy than ZSM, for example the modern Brandhorst Museum in Munich[5] which was opened recently (Ottitsch, 2009a).

Legal and Social Framework

To understand the whole situation, it is necessary to know the general legal and social situation in Germany. There is nowadays a strong social agreement to save energy and to support “green” energy techniques like solar energy in Germany. Furthermore, there is a trend towards growing economic liberalism, but many things are strictly regulated. It should be added that there are a number of different means of financial support for “green” energy from cities, states and the federal government in Germany, but it is beyond the scope of this communication to list them.

Political hierarchy: Most laws in Germany are valid for the whole federal republic (Bundesrepublik, BRD), but there are also laws made by the European Union, and by the states (i.e. parts of BRD, in our case Bavaria). Also the cities have certain powers, such as controlling the use of the groundwater.

Each of the different tiers can and does contribute to energy saving. For example there is a program of the city of Munich (and many others) to support financially private people who install solar panels on their own roofs. As an other example, the actual energy-saving law of the BRD (“Energieeinsparungsgesetz”) was necessary because of a directive of the European Union which regulated (e.g. “Eneregieeinsparverordnung”) how newly built houses have to be constructed so that they do not need too much energy for heating. In certain cases, if a very old heating system wastes energy, it has to be replaced.

[5] http://www.museum-brandhorst.de/en/building.html

Energy market: The energy market in Germany is deregulated, which means you can choose a company from which you buy your electric power. Thus, the department which administers the buildings which belong to the government of Bavaria can bargain for buying electricity for all official buildings in Bavaria. Hence ZSM gets a special price for electricity.

On the other hand, a law of the federal government ("Gesetz für den Vorrang Erneuerbarer Energien") says that the company which you buy the electricity from must buy any electricity that you produce, whether by means of photovoltaic cells or as in our case by cogeneration, for a special price which is higher than the normal price. A large part of the price for energy is a special tax (energy tax), but the gas which you use for cogeneration is free of energy tax. This strongly supports the use of such techniques.

Ground water: The use of ground water for heating and cooling is strictly regulated by the city authorities. We have to pump the water back at the same depth from which it was pumped; we need a permit and are only allowed to use a certain amount of water. We are allowed to lower or increase the water temperature by a maximum of 5K, with a maximal temperature of 20°C. All this is to ensure that different users do not interfere and disturb one another.

Political intention: The public administration has a special responsibility to support energy saving techniques in public buildings. Therefore the public administration (in our case the government of Bavaria) can provide special money for such investments.

General Outline of New Central Power Station

The new central power station (figures 7-11) was installed in 2006. It was planned for maximal efficiency by specialized engineers (Ingenieurbüro Robert Ottitsch, München) and has the following main components which are outlined in a schematic figure (figure 12, see also Ottitsch, 2009b):

Cogeneration (or combined heat and power, CHP, figure 9) is driven by natural gas and produces both heat (hot water of about 85°C) and electricity. The electricity produced is mostly used in ZSM, but if not needed, fed into the public network. The hot water can be used for heating the rooms in winter or to drive the absorbing heat pump. Technical data: production of 115 kW heat and 70 kW electricity, ca. 90 % total efficiency factor. Throughout the year this CHP produces about 50 % of the total heating energy.

An **absorption heat pump** (ca. 80 kW refrigerating capacity, figure 7 left) is driven by the hot water from the cogeneration process. This produces cold water for cooling purposes in air-conditioning and is warming up groundwater. This system can provide about 40 % of the necessary refrigerating capacity.

A second, **electrically driven heat pump** (compression heat pump, 120 kW output, 40 kW electricity uptake), which also uses groundwater circulation, can produce cold water for air-conditioning in summertime and hot water for heating in wintertime.

Furthermore, for security and if the winter is very cold there is a **gas fired condensing boiler** (figure 8 left) as an independent heating system (the output of which can be modulated between 70 kW and 450 kW). A gas fired condensing boiler has a very high operating efficiency by using the energy recovered from the condensation of the water vapour in the exhaust gases.

To enable optimal running times for the cogeneration and heating pumps different thermal energy storage systems are needed. There is a high temperature reservoir using paraffin **(phase change material)**, which melts at 70°C, and can store enthalpy of fusion. **Reservoirs for hot/cold water** are also installed, a 4000 l buffer with warm water (50°C) and a 2000 l buffer with cold water (6 to 12°C)(figure 12).

A part of the warm service water is produced by an electrical heating system supported by a **solar panel** of ca. 12 m^2 on top of the ZSM roof (figure 6).

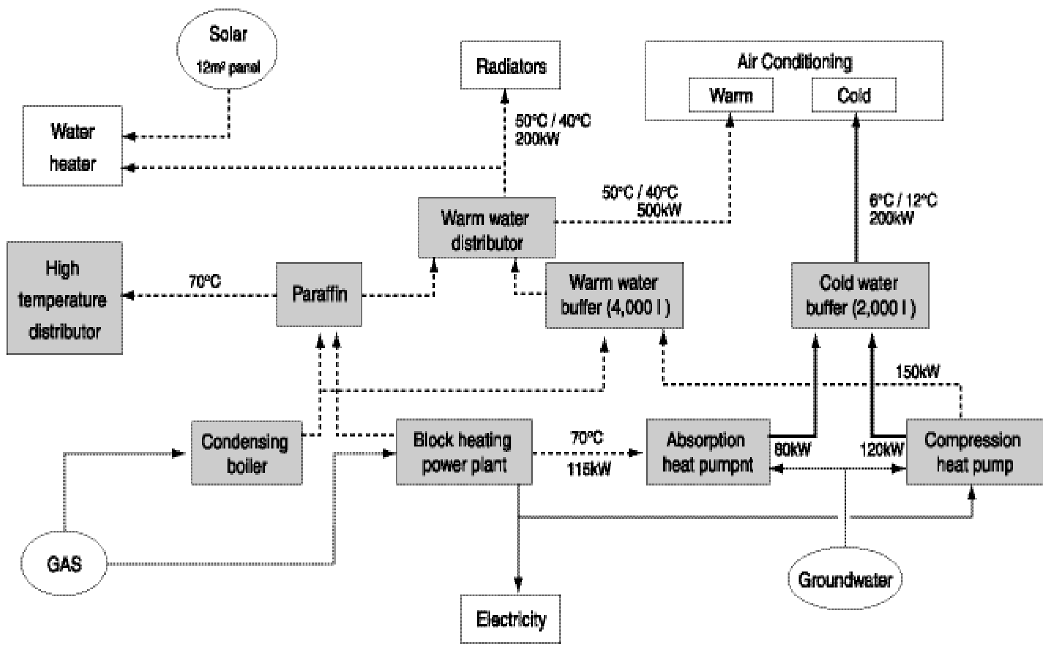
Figure 7. Absorption heat pump (left), and cogeneration equipment (right) .

Figure 8. Gas fired condensing boiler (left) and absorption heat pump (right).

Figure 9. Cogeneration equipment.

Figure 10. Warm water distributor.

Figure 11. Central control system.



inputs

output

the components of the station

the flows of gas and groundwater

the flow of electricity

the flow of cold water

the warm/hot water

Figure 12. Scheme of the central power station. As a driving power, the inputs of electricity are necessary nearly everywhere therefore the inputs of electricity have been omitted in the scheme (Only the main flows are shown, e.g. from "High temperature distributor" there are several outputs which are not shown for the sake of simplicity, such as the important flow to the "Absorption heat pump").

The whole system is controlled by a **computerized central control system** (figure 11) which records altogether 750 data (like temperatures of the different water cycles and the status of the different components) and controls all parts of the system. This control system continuously shows on its screen the most important energy and water flows and their temperatures. It indicates if any maintenance is necessary or anything does not work. Many of the data are automatically stored for analysis of any mistakes or problems.

Amount of energy saving and further plans

The amount of energy saved by the new devices was calculated by Ottitsch (2009b): during the years 2001 to 2005 (before the new system was established) ZSM used 1,338 MWh gas per year. In the years after (2006 to 2007) 1,582 MWh gas was needed, i.e. an additional need of 244 MWh of gas per year. The extra gas was used in CHP, but this has reduced the need for electric energy from 931 MWh to 509 MWh, i.e. 422MWh electric energy been saved per year. Thus, despite the use of more gas, we clearly can save much energy. It was calculated that the additional cost of this new central power station as compared with a conventional system will have been repaid within some 3.5 years (Ottitsch, 2009b). It is calculated that the actual system is saving about 100,000 kWh per year, which is equivalent to an annual reduction of about 27t CO2 (Oberste Baubehörde, 2008).

Because all air conditioning equipment is still as built in 1984/85 and thus is not well regulated (e.g. the efficiency of any pumping systems can not be regulated but only be switched on/off), there is certainly still a lot of energy-saving potential. The whole system is planned to be renewed for enhanced energy efficiency within the coming year.

Acknowledgements

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博物館節能減碳範例
——慕尼黑動物學蒐藏研究中心

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摘要

慕尼黑動物學蒐藏研究中心（ZSM）是德國主要的動物學蒐藏研究機構之一，超過兩千萬件的標本蒐藏，使其躋身世界最大動物蒐藏之列。ZSM的成立宗旨即為妥善保存動物學標本及大量的生物學資訊，並確保這些資訊能為科學家及一般大眾利用。

ZSM目前的館舍於1985年竣工，該建築以完善的蒐藏庫為設計重點，並體現出綠建築的精神。本文旨在介紹該建築在德國的社會背景及相關的環保法規下，實踐節能減碳的方法。

該館舍以建築體及電力系統雙管齊下，達成綠建築的目標。在建築體方面，低於地面的雙層館舍易於維持建築物內部穩定的溫溼度；在電力系統方面，於2006年安裝完成的新系統，包括利用天然氣產生電能的氣電共生系統，以及電腦控制中樞。除此之外，利用地下水來加熱或冷卻系統，亦為此套電力系統的重要優勢之一。

關鍵詞：節能減碳、綠能源、綠建築、氣電共生、自然史博物館

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本文旨在介紹慕尼黑動物學蒐藏研究中心（Zoologische Staatssammlung München，以下簡稱 ZSM）[4]在能源利用上如何達到兼顧環保與經濟效益之極至，以及本議題所涉及之社會背景與環保法規。希望本文的介紹能為臺灣在綠建築及節能減碳設計上提供一些參考。

ZSM 是德國主要的動物學研究機構之一，標本蒐藏達兩千萬件，為世界最大、歷史最悠久的動物學蒐藏之一。ZSM蒐藏的標本大部分是在過去兩百年間，由館方的研究人員及其他與ZSM互動良好的蒐藏家採集得來。該機構的成立宗旨即為妥善保存這些標本及其中大量的生物學資訊，並確保這些資訊能為科學家及一般大眾利用。ZSM的研究範疇涵蓋分類學、生物親緣及動物演化等，為確保研究人員能有足夠且適當的材料持續進行研究工作，提供完善且充足的標本蒐藏空間即為該機構的終極目標（劉藍玉，2008）。

ZSM雖然不算是博物館，但也會在館內大廳及迴廊等空間，定期或不定期提供與動物學相關的展示、開放給一般大眾的演講、動物學家的聚會，並為提出特別申請的學生團體或專業人士做深度導覽，以及其他服務民眾的教育活動（劉藍玉，2008、2009）。此外，多位館方研究人員亦於慕尼黑大學（Ludwigs-Maximilians-Universität）開設動物學及生物多樣性相關課程，並擔任該大學的學士、碩士或博士班學生的論文指導教授；現任館長更兼任大學動物系主任。由此可知ZSM和慕尼黑大學雖為兩個獨立的學術單位，但在學術上卻有緊密的合作關係。

研究中心歷史背景

ZSM奠基於1759年，為當時巴伐利亞地區的統治者馬克思米立安三世（Maximilian III Josef，統治時間1727-1777）專為蒐藏自然史標本而成立的學術機構。該機構於 1807年進行擴編改組，馬克思米立安一世（Maximilian I Josef，1756-1825，巴伐利亞地區首位國王）更於1811年任命年輕的動物學家約翰．巴布提斯．史匹克斯（Johann Baptist Spix，稍後更名為 J. B. Ritter von Spix，1781-1826）執掌動物學蒐藏，此乃ZSM身為巴伐利亞動物學研究機構的開端。約翰於 1817至1820年間，與植物學家卡爾．佛德瑞希．馬提爾斯（Carl Friedrich Martius, 1794-1868）共赴巴西採集，並帶回大量標本，目前存放於ZSM、巴伐利亞植物學蒐藏中心及慕尼黑州立民族學博物館（Fittkau, 1992）。

ZSM原先與一間公立博物館及後來的慕尼黑大學動物系的前身機構，共用一棟位於慕尼黑市中心的建築（Wilhelminum），該建築毀於二次大戰的砲火中（Kraft & Huber, 1982）。所幸大部分標本在砲火轟炸前，都已運至市郊的礦坑或防空洞中，因而逃過一劫。戰後ZSM在寧芬堡(Castel Nymphenburg)的廂房暫時棲身，直到1985年位於市郊的新館舍落成（劉藍玉，2008）。

綠建築館舍

ZSM的新館舍工程於1981年開工，1985年竣工，首要的設計重點乃為兩千萬件館藏及龐大的生物學資訊打造

[4] 本文中的慕尼黑動物學蒐藏研究中心即為巴伐利亞州立動物學蒐藏中心（Bavarian State Collection of Zoology）。

最完善的保存環境（ Suarez & Tsutsi, 2004)。兩層樓高的館舍不只立基於地面以下，甚至連二樓屋頂都稍低於地面（圖1、4)，僅演講廳高出地面（圖5)。低於地面的館舍設計有節省能源等考量，同時也可避免高聳的館舍遮擋周圍居民的視野（圖3)。

館舍由兩棟大型圓形建築組成（圖2)，圓心中央為天井。研究人員和工作人員沒有空調的辦公室都圍繞著天井，以便採用自然光。蒐藏庫則位於圓圈外圍，緊鄰土壤層，設有空調及警報系統（圖2)。蒐藏庫共23間（包括圖書館及一間挑高兩層樓的蒐藏庫)，總蒐藏空間約5,100 平方公尺。不同類的標本（如昆蟲針插標本、哺乳動物骨骼標本、毛皮標本以及浸液標本等）蒐藏庫，各有不同的溫溼度控制條件。另有70個房間

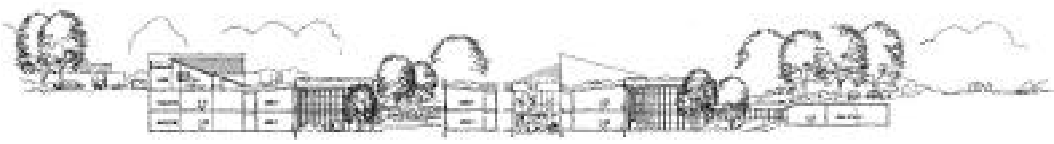

圖1. ZSM館舍側面圖。

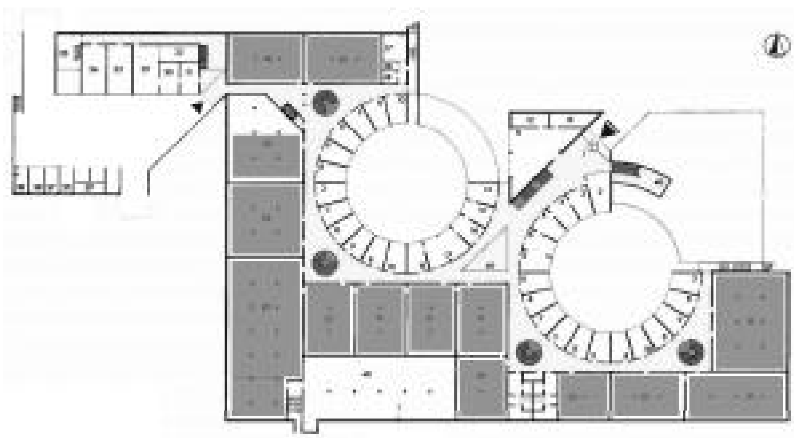

圖2. ZSM館舍一樓平面圖。灰色部分皆為蒐藏庫，箭頭所指為大門入口。

圖 3. ZSM及周圍住家空照圖。“X” 標示出地下水唧出及壓回位置（Erwin Lehmann 攝)。

是館內人員（包括研究人員和行政人員）及客座研究員的辦公室、研究室、實驗室和工作室等空間。館舍總使用面積約為11,000 平方公尺（ Fechter, 1992; Ruthensteiner, 1999）。

為了工作效率起見，蒐藏管理人員及技術人員的辦公室均靠近其負責管理的庫房，而行政中心及圖書館等公用空間，則設於兩個圓形建築的交接處，緊鄰主要出入口（圖2、4、6）（Ruthensteiner, 1999）。

德國的氣候比臺灣寒冷，因此德國的建築不像臺灣的建築，夏天時需要很多能量做為空調之用，反而是在冬天才需要較多能量做為暖氣之用。與一般高於地面的建築比起來，ZSM地下化的館舍因為四周都有溫度變化相當穩定的地基保護，可以節省不少暖氣系統所需的能量；此外，屋頂大部分都有草皮覆蓋，有助於穩定建物內部的溫度。因此，ZSM館舍目前已經成為德國境內相當有名的綠建築之一（Grub, 1990）。

ZSM館舍從設計規劃到施工完成（1978-1985）這段期間，正逢全球能源價格飆漲。館方考慮到能源有限，未來價格只可能繼續上漲，因此特別在電力

圖4. ZSM通往地下館舍的大門入口（M. Müiler 攝於冬天）。

圖5. ZSM館舍的夏季外觀。可以看到三角形的演講廳屋頂。

圖6. 兩棟圓形建築之一的天井，右下方為圖書館，後方為演講廳的三角形屋頂，以及太陽能電板。

系統中加裝了天然氣熱泵(Heat Pump)[5]，以節省能源並做為「氣電共生」系統。這套系統在規劃當時算是相當新穎但技術不夠成熟，因此在操作和維修上碰到很多問題，經過數次更新，全新的系統終於在 2005-2006 年間安裝完成。這套電力系統一開始就配合利用地下水資源做為能量轉換的媒介之一；亦即由地面下10公尺深處唧出地下水，以做為冷卻或加熱系統之用，之後再將等量及近似溫度的水壓回另一頭同樣深的地層中，唧出及壓回地下水的兩點相距約 200公尺。這套利用地下水為熱能媒介的系統，僅用於降低電力系統的溫度，因此在能量轉換上可算是游刃有餘。

德國一向致力於開發更新更節能的電力系統，因此要打造一座綠色博物館已不是問題，而且在節能減碳的效能上，絕對可以比 ZSM更優異。新近於慕尼黑落成的布朗德荷斯美術館(Brandhorst Museum in Munich)[6]就是一個很好的例子(Ottitsch, 2009a)。

法規與社會背景

一旦對德國在節能減碳方面的相關法規及社會共識有了初步認識，就能對德國的綠建築發展有較全面的瞭解。現今德國社會對節能減碳的努力有強烈共識，並以實際行動大力支持所有「綠能源」技術的發展，例如太陽能。此外，雖然經濟自由化的風氣持續高漲，但很多事情仍受到嚴格的規範。德國政府從市、邦到聯邦各層級，都提出若干獎勵及規定，以支持「綠能源」，由於本文主要目的並不在於介紹所有相關獎勵與法規，因此僅列出其中較為重要的觀念及執行方式。

各級政府法規

德國大多數法案都由聯邦政府(Bundesrepublik, BRD)制定，但也有少數法案由歐盟政府或邦政府(BRD的一部分，像慕尼黑即隸屬巴伐利亞邦)制定。市政府也有一定的權限，像是控管地下水的使用。不同層級的立法都對德國節能減碳的努力做出一定的貢獻，例如慕尼黑市政府(以及其他許多市政府)便訂有獎勵條款，補助私人於住家屋頂安裝太陽能電板。而在另一方面，聯邦政府也必須根據《能源管理法》(Energieeinsparungsgesetz)訂定節能減碳的施行細則，這項法案是依據歐盟的《能源管理條例》(Eneregieeinsparverordnung) 制定的，該條款規定新建築都必須符合綠建築的標準，以便減少暖氣的消耗量。在某些案例中，消耗過多能源的舊式暖氣系統都必須更換。

能源市場

德國的能源並未實施專賣；換句話說，消費者可以在眾多販售電力的公司中做選擇。因此，巴伐利亞邦政府中負責管理政府建物的部門，可以為所有政府建物集體採購電力，並以大量採購的方式壓低進價，ZSM也因而享有較優惠的電力。另一方面，聯邦政府的《再生能源法》(Gesetz für den Vorrang Erneuerbarer Energien)則規定電力公司得無條件買回客戶自行生產的電力，像是藉由太陽能電板，或是像 ZSM利用「氣電共生」系統生產的電力。對 ZSM 來說，由於巴伐利亞政府採用集體議價

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[5] 譯註：熱泵又稱冷機(refrigerator)，將能量由低溫處傳送到高溫處的裝置，且提供給高溫處的能量和，大於它運行所需要的能量(資料來源：維基百科)。

[6] http://www.museumbrandhorst.de/en/building.html

的方式，讓ZSM也能以高於一般市價的價格將電力售回。在德國的電費費率中，特別稅（能源稅）占了很大一部分，不過用於氣電共生的天然氣可免繳能源稅。這項免稅規定鼓勵了民眾大力支持「電氣共生」，這項新的能源再生技術。

地下水資源

在德國，地下水的使用受到市府法規嚴格的控管。除了必須領有使用執照外，每張使用執照核發的使用量也不同。所有使用過的地下水都必須再壓回與唧出處一樣深的地層中，壓回的地下水溫度不得高於或低於唧出時的絕對溫度5K，且水溫不得高於20°C。所有與地下水相關的規定，都在確保水質及水量的穩定。

政府經援

德國公部門必須負責支援公共建物中的節能減碳技術及設備，因此直屬的上級單位（ZSM的直屬上級單位為巴伐利亞邦政府）會對轄下單位提出的相關研究、調查及更新計畫案，提撥特別預算。例如ZSM不久前才申請到一筆特別預算，作為更新館舍的舊空調系統之用。

中央電力系統簡介

ZSM館內的中央電力系統（圖7-11）於2006年安裝完成。該系統由專業的電力工程公司（Ingenieurbüro Robert Ottitsch, München）設計，目的在於讓使用到的所有能源都能發揮最大的效用。該系統的主要設備及效能簡述如下，整體機械運作方式如圖 12所示（Ottitsch, 2009b）。

氣電共生系統或稱熱能共生（combined heat and power, CHP；圖9），係由天然氣驅動的系統，可以產生熱能（約85°C 的熱水）及電能。此系統產生的電能為ZSM的主要電力來源，若產生多餘的電力（尤其是在不需要使用暖氣的夏天），則可售回電力公司，供其他電力用戶使用。系統產生的熱水可用於館舍內的暖氣系統，或是驅動吸收熱泵（absorption heat pump）。此系統使用能量的效能約為90%，每年生產115千瓦的熱能及70千瓦的電能，可提供館舍終年所需的50%熱能。

吸收熱泵其冷卻能約為80千瓦（圖7左），由氣電共生系統產生的熱水驅動，產生的冷水與剛唧出的地下水，皆可供蒐藏庫的空調系統使用。此設備可供應全館40%用於冷卻的能量。

另外一組熱泵是**電力驅動熱泵**（壓縮熱泵， compression heat pump，輸入40千瓦電力，輸出120千瓦能量）；這套設備也使用地下水循環做為能量介質，夏天可提供冷水做為空調之用，冬天可提供熱水做為暖氣之用。

此外，萬一碰到非常嚴寒的冬天，還有獨立的**天然氣壓縮鍋爐**（gas fired condensing boiler，圖8左）可供暖氣系統使用，其產能可在 70到450瓦之間做調整。天然氣壓縮鍋爐使用抽出氣體中濃縮水蒸氣的能量，能源轉換效率很高。

為了使氣電共生系統和熱泵達到最理想的運作，中央電力系統還需要設置不同的熱能儲存系統。此套電力系統採用石蠟**（相變化物質）**做為高溫儲存庫。石蠟會在70°C 時融化，並儲存融化的焓。另外也設有**熱／冷水槽**，有4,000公升的溫水（50°C ）和2,000公升的冷水（6-12°C）做為緩衝。

裝設於ZSM屋頂上12平方公尺的**太陽能電板**（solar panel，圖6），可驅動加熱器生產館內日常使用的溫水。

整套電力系統都由**電腦化的中央控制系統**（computerized central control system，圖11）管控。這套電腦系統可

圖7. 吸收熱泵(左)及氣電共生系統(右)。

圖8. 天然氣壓縮鍋爐(左)及吸收熱泵(右)。

圖9. 氣電共生系統。

圖10. 溫水分流設備。

圖11. 電腦化中央控制系統。

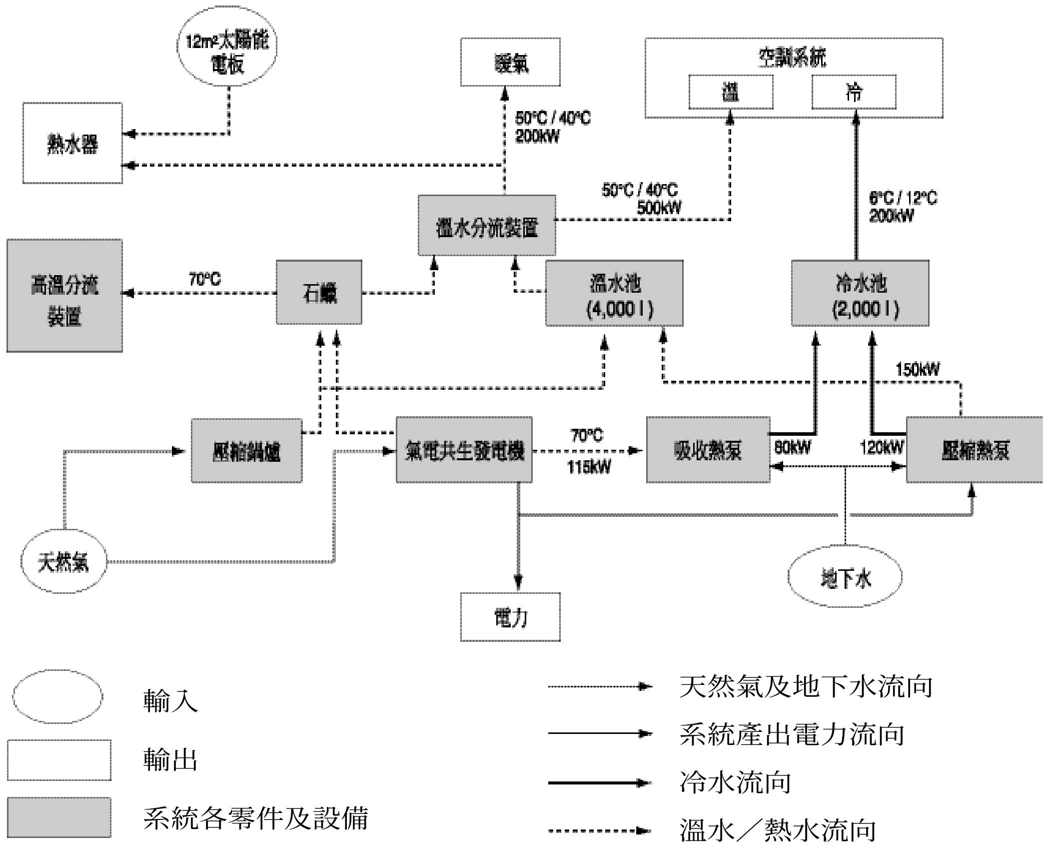

圖12. 中央電力系統運作圖解。電力是此系統的主要驅動力，幾乎所有裝置都需要輸入電力，因此本圖中也省略電力的輸入圖示。（為了簡化此圖，本圖中僅列出能量的主要流向，例如從「高溫分流裝置」輸出的能量尚有多處，其中比較重要的流向是朝「吸收熱泵」輸送，圖中並未列出。）

以記錄750筆資料（例如不同水循環的溫度，以及不同設備的狀況），並掌管中央電力系統每個工作環節。這套電腦設備隨時都會在螢幕上顯示最重要的能量流和水流及其溫度，管理人員可依此看出系統是否出現異常狀況，以進行維修。電腦記錄下來的所有資料，都會自動儲存到硬碟，以便日後分析問題之用。

節能成果與未來展望

這套新電力系統的節能成果，已經由Ottitsch（2009b）統計出來：2001-2005年間（新系統安裝前），ZSM每年使用1,338仟度（MWh）天然氣；新系統安裝後的2006和2007兩年，每年需要1,582仟度的天然氣。換句話說，新系統每年對天然氣的需求量比舊系統多 244仟度。多出來的天然氣主要用在氣電共

生系統，讓ZSM對電力的需求量由之前的每年931仟度，下降到509仟度，亦即每年對電力的需求減少 422仟度。因此，ZSM的新電力系統雖然需要較多的天然氣，但也很明顯地省下了更多電力。此外 Ottitsch（2009b）也統計了ZSM為新電力系統額外投資的預算，跟一般的舊式電力系統比較起來，可以在3年半內回收。另外一項節能減碳的統計也指出，這套新電力系統每年大約省下10萬度（千瓦小時，kWh）能量，相當於減少了 27噸二氧化碳的排放量(Oberste Baubehörde, 2008)。

目前ZSM庫房使用的空調系統都是於1984/1985年間設計安裝的舊系統，尚未隨新電力系統更新，也不能做溫度調整。換句話說，所有空調系統都只有「開／關」控制，而不能依溫度做微調。因此，我們可以確定ZSM仍有極大的節能減碳空間，希望ZSM可以在未來幾年內完成空調系統的更新工程，省下更多能源。

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