

## **Research on the usage of seawater from subsurface current as The natural cold resources for a city's regional air-conditioning systems**

*Jie Ma      Jiandong Zhang      Qiaoling Kong      Du Lele      Ni Yuanfang*  
School of Naval Architecture, Ocean & Civil Engrg, Shanghai Jiao Tong University  
1954 Huashan Road, 200030 Shanghai, P.R.China, [jma@sjtu.edu.cn](mailto:jma@sjtu.edu.cn)

**Abstract:** The temperature distribution of seawater in China's coastal waters and over the world indicates that the subsurface layer of the oceans contains a great mass of cold seawater. The seawater from the subsurface current can be used as the cold resources of air-conditioning systems in the whole urban area, so that the city can achieve free refrigeration effect and then, its local climate can be affected. According to thermodynamic principles of the refrigeration cycle and analysis of exergy efficiency, this scheme's advantage could be manifested. For this scheme being realized, however, several correlative researches should be carried out in advance, such as, the flow and heat transfer properties of the subsurface current, drawing in and draining off seawater's effects on the subsurface layer's local temperature and flow field, the short-term effects and the permanent influence to ocean's ecological environment.

**Key words:** subsurface current, seawater, natural cold resource, urban area's air-conditioning

### **1 Background**

In summer, a great amount of energy resource is consumed by air-conditioning systems. Especially in the developed countries, such as American and Japan, it accounts for about 1/3 of the total consumed energy. Together with the energy consumed in winter, it somewhere even reaches 45% of the total consumed energy, e.g., in Sweden. The majority of energy consumed by air conditioning in summer is used for equipments' cold resources, the rest for its power system. The energy consumed, from a large sum of natural resources, turns to waste heat at last to raise the environment temperature. Meanwhile, the atmosphere is polluted. As the weather over the world warmer and warmer, the urban temperature reaches its highest point in hot summer in many cities and comes to be a threat to human health and human lives.

A large amount of energy expense for its cold resources occupies a main part of the air conditioner's energy consumption. Recent years' summer, many cities and provinces in China emerges peak load of electricity consuming. Serious shortage in supply of electricity forced 19 provinces to adopt a strict restriction of electricity usage in 2003. The following year, even some metropolises, constantly adequate on supply of electricity, had no choice but to constrict large areas' usage once and once.

Residents and national economy there were affected severely. To overcome the difficulty essentially, increasing electricity supply is an enormous project, not the optimal way.

## **2 Ocean is a resources of infinite cold energy**

### **2.1 Ocean has a huge potential to adjust urban climate**

China has a coastline of 18,400 km, or 32,000 km including islands and islets' shoreline, hundreds of coastal cities along the shore. On the land, broiling summer brings persons masses of trouble. They have to pay for a huge amount of energy to cool narrow rooms in scattering space for resisting the insupportable threat. Under the surface layer, a great mass of cold seawater is lying silently, cold, clean, involving infinite natural cold resources.

Ocean obviously has a great potential to adjust urban climate.

According to meteorological data, climate in coastal cities may conspicuously be improved under the action of appropriate wind and ocean current. For instance, Dalian, a city located at the shore of Bohai Bay is warm in winter and pleasantly cool in summer. Without appropriate wind or ocean current, however, ocean can not take positive adjusting effects to the climate around coastal cities. For instance, Tianjin, a city located at the shore of Bohai Bay and the same latitude, is not of comfortable climate <sup>[1]</sup>. Even if wind favored the weather, the cold subsurface current of seawater which is covered by surface layer's seawater of higher temperature can not absorb atmosphere's heat to adjust city's weather. It is clear that most coastal cities are hot in summer, China.

### **2.2 Subsurface current is the natural cold resources of air-conditioning.**

The scheme of seawater from subsurface current as natural cold resources for urban area's air-conditioning (SWCR) means bringing seawater from subsurface current into cities in summer and utilizing its natural cold capacity directly for the whole urban area.

The shallow layer's seawater is cold enough even in a hot season. The seawater from subsurface current is, under the surface layer, at a limited depth and easy to fetch. It can be directly used as a cold resource of air-conditioning system in urban area.

In detail, the Bohai Sea, at an average depth of 18m, stratifies dramatically in summer and the temperature of each layer increases distinctly. But, the temperature of the seawater from subsurface current is much lower. On the west of Liaodong Peninsula and north of the Strait of Huanghai, the temperature of surface seawater is lower than 20℃ because the tide strongly mixes each other to form a low temperature section <sup>[2]</sup>, which is a natural cold resource of air-conditioning.

In summer, Huanghai Sea is occupied by cold water of 6—12℃ from thermocline to bottom. It is the most suitable natural cold resource of urban air-conditioning. In Huanghai Sea's deepest part there are several cold centers, including one in north of Huanghai Sea, each one in the east and west part of southern Huanghai Sea respectively. The east one, with a central temperature below 6℃, has a little variation of location in whole year's time and the west one, with a central temperature below 7℃,

swings on longitudinal orientation and has a variable location from year to year.

The temperature distribution's characteristics of East China Sea and the meteorological condition on the sea are related to the variation of run off from rivers, as well as the presence and mutation of Japan Current and its tributaries. According to the vertical distribution of temperature, the seawater can be divided into four layers: surface current, subsurface current, middle layer's current and deep layer's current, of Japan Current. Surface current of Japan Current has homogeneous characteristics with a depth of 0—150m.

The seawater under the surface has a stable property around the year with a temperature range of 15□ to 20□, a depth of 150m to 400m. It is convenient to be a natural cold resource for urban air-conditioning. The depths of middle layer and deep layer of Japan Current are 400—800m and below 800m respectively at temperature of 6—15□ and 3.8—6□. Although the temperature is lower, it is poor economy to fetch them from its depth. East China Sea's deep layer has a homogeneous hydrological distribution with a lower temperature and a larger depth than the middle layer.

Generally, the seawater from East China Sea's middle layer and deep layer does not intrude in continental shelf. However, summer's thermocline in East China Sea is strong because the temperature of surface seawater increases fast, and meanwhile the seawater from subsurface current that possesses a property of low temperature intrudes into the continent shelf. The depth of thermocline is about 10m near the shore and increases gradually with the distance away the coastline until it reaches the Japan Current Area, where its depth is about 100m. Such a variation of the depth is beneficial to the economy of SWCR project.

Under the thermocline in the north of East China Sea's shelf, there remains cold water formed in winter. In other part of the Sea, there exists widespread seawater from subsurface layer of Japan Current. The former is at 12—15□ and the latter at 17—18□. They occupies a broad area, which is 100—200m deep from the north of Taiwan, lengthens to the west of Japan Archipelago.

Taiwan Strait connects East China Sea and South China Sea, the west is mainly affected by the seawater of East sea coast while the east is rarely affected by South China Sea. In summer, due to the strong solar radiation, its stratifying structure is obvious. Under the thermocline, is seawater at 22—24□. The seawater of middle and deep layer on the west of the Strait is at a lower temperature than on the east. Upwelling occurs on the bottom around the west of the Strait, so that the current at about 25□ can climb up to 20m deep, which raises this area's temperature a little bit higher. Therefore, the coastal cities to south of Fuzhou in Fujian Province would have less advantage in SWCR.

The basin area of South China Sea lengthens to the north of Nansha Islands. This basin's cold deep water goes from Pacific Ocean's South Philippine Sea in the east of Bashi Channel, through the passage above the depth of Bashi Channel's tectogene, at last to the basin area of South China Sea. The current keeps temperature constantly around the year..

Along the vertical orientation, the basin area can be divided into four layers:

surface current, subsurface current, middle layer's current and deep layer's current, of South China Sea. Subsurface current is under the surface layer, 100m to 300m deep. Its main feature is a constant temperature range from 12°C to 20°C, with little seasonal variation. On the north shelf and slope of South China Sea, the seawater's temperature characteristic is complex; the temperature fluctuates in four seasons.

The anaflow area on the east bank of Hainan Island is the scope of the lowest temperature of surface current along southeast China's coastal area; It is often below 20°C and the temperature is relative to continuous southwest wind. In summer, an upward current, 70km to 90km wide, may emerge in a 30m to 100m deep layer in littoral near Santou and the shoal of Taiwan. The upward current is located at the edge of the South China Sea's shelf. In summer, seawater from lower layer of South China Sea's shelf, at 21°C to 27°C, intrudes into the lower layer in the Gulf of Tonkin, which has the scope of cold water mass lessen.

In brief, the subsurface current near the coastal in China is at 12—20°C, even below 6—12°C and 10—300m deep. It is an excellent natural cold resource of air-conditioning for urban area on a large scale [3].

Referring to global distribution of annual average temperature on sea surface and global vertical distribution of annual average temperature on broadwise position, there is a prerequisite for a widespread realizing of SWCR scheme over the world. Even though the temperature of sea surface is a little higher in the area between 30° northern latitude and 30° southern latitude, the seawater down to a depth of 100m to 120m may still maintain the temperature below 22°C—24°C. Comparing to the record of seawater temperature's variation [15], the highest temperature around a year appears in September but not in summer even if sea surface's temperature fluctuates with seasons. The temperature of seawater in subsurface current layer and near subsurface current layer is almost constant. It is favorable to SWCR scheme's universal application.

### **2.3 The seawater cooling technology needs improving**

The existing seawater cooling technology, mainly for seawater's direct cooling, has been applied in industry. In the Europe and North America, seawater direct cooling by original seawater as cooling medium has already been applied in industry for nearly one hundred years [4]. Similarly, it has been used for 60 years in China [5]. Due to the difficulties from corrosion, encrustation, fouling organism and salt sediment, it is laborious to popularize and apply circulating cooling technology. Several countries attempt to develop this technology towards large scale's application for benefiting environment [6]. In China, however, this technology is still at a step of research and demonstration. National Bureau of Oceanography and some universities have already finished preparation for one hundred ton-level's demonstration [7]. They got some achievements from the key technology of direct and circular cooling, of water resources crisis's solving [8], corrosion's preventing etc. All the technology mentioned above is limited to the cooling for industry and utilizing of seawater from surface current [9].

It seems that a large scale's developing and utilizing of ocean as cold resources of air-conditioner does not begin. Some countries' researchers attempt to bring

seawater into urban area to built a cooling system <sup>[10]</sup>, and pay much attention to the usage of deep seawater also <sup>[11]</sup>. However, SWCR scheme is more direct and easier to realize.

### **3. Process and analysis of SWCR scheme**

#### **3.1 The process of SWCR scheme**

For overall installation's performing SWCR scheme needs to set a series of suction ports extending to sea at different depths, to pump a great amount of seawater from the subsurface current of a low enough temperature, to treat the pumped seawater through a preprocessing procedure, and to transmit seawater into an adiabatic reservoir through the adiabatic pipe network.

In detail, a series of water entrances are laid under the ground at different depths below the sea level according to the depth of local subsurface current. While the temperature of seawater at a certain depth meets the needs for air-conditioning, the water entrances at the same depth begin to work and the others below this depth will stop working for energy saving. While seawater at this depth is not cold enough, the entrances at and above this depth will be closed. Through entrances at a deeper depth seawater will be pumped into the adiabatic storing units, and then be brought upward into the adiabatic channels.

The adiabatic channels may be a pipe network buried under ground, or the river courses, low-lying land in mountain range and river valleys, which have been treated for percolation-proof and sealed by covers <sup>[3]</sup>. The cold seawater is pumped into a preprocessing equipment, passes through mixing, coagulating, depositing and filtering procedures. Then it is the sent to adiabatic storing units buried under the ground through adiabatic channels <sup>[12]</sup>.

The seawater reservoir is a centralized room, or a series of small pools in separated rooms <sup>[14]</sup>, connected by each other. The underground Karst caves and confined aquifer layers are excellent natural geological structures to be the reservoir. A part of seawater flows from reservoir to transmit a great amount of cold capacity to urban air conditioning system by means of heat exchangers, and the rest is sent to sprinklers, fountain pools, flumes and artificial lakes for absorbing heat from environment as much as possible.

When it is warmed and closed to normal temperature, the used seawater will be drained into the special processing devices for filtrating and post-processing treatment. At last, it flows back the sea.

#### **3.2 The benefits of SWCR**

For example, according to Shanghai's statistical data from the power branch, the local power consumption was 68.499 billion Kw.h per year in Shanghai, and 30% of the power was consumed by air-conditioners. If 25% of the total is applied to air-conditioning, about 17.12 billion Kw.h at least is consumed by air-conditioners.

That is,  $6.16 \times 10^{13}$  KJ of extra heat load from air-conditioners' operation is increased in Shanghai. It is a considerable amount. Recently, air conditioning is the main cause for the power network's overload in summer.

Referring to the national standards, working performance coefficient of air-conditioners may be 2.57. Then, 25% of the total power consumption in Shanghai may produce  $1.58 \times 10^{14}$  KJ cold capacity. Namely, the amount of heat at ordinary temperature will be warmed to a condensation temperature of refrigeration cycle and releases into atmosphere. Together with air-conditioners' power consumption, the total amount of heat of  $2.196 \times 10^{14}$  KJ releases to the atmosphere, which may raise the temperature of Huangpu River of  $5.287 \times 10^{10} m^3$  volume's water by 1 °C.

It is known that a work-consumed cycle's efficiency of the second law of thermodynamics is, indeed, a ratio of actual thermal efficiency to the maximal thermal efficiency under the same working conditions. It can be stated as

$$\eta_{11} = \frac{W_{rev}}{W_u}$$

This efficiency is synonymous with the exergy efficiency. Here,  $W_{rev}$  is the work wasted by the reversible cycle;  $W_u$  is the useful work wasted. For refrigeration cycle, this equation may be stated as:

$$\eta_{11} = \frac{COP}{COP_{rev}}$$

Here, COP is the coefficient of performance of actual refrigeration cycle;  $COP_{rev}$  is the coefficient of performance of reversible refrigeration cycle under the same conditions. Analyzing Carnot refrigeration cycle, we may get:

$$\eta_{11} = \frac{COP}{(T_H / T_L) - 1}$$

Here,  $T_H$  and  $T_L$  are the cycle condensation temperature and evaporation temperature respectively. While  $T_H$  lows steadily, even closed to  $T_L$ , the efficiency will reach a very high value. This is just the situation of SWCR.

If the scheme of air-conditioning equipment is substituted with directly drawing seawater from subsurface current at a lower temperature for absorbing heat and climate regulating, the electric power consumed is just for the forced flow of the fluids and so, is reduced by a large margin. Another scheme, conveying seawater to separate sprinkling stations and artificial lakes for absorbing heat from the environment, is exactly the condition mentioned above.

#### **4. Conclusions and prospects**

There is no reason for worrying about SWCR scheme to aggravate El Nino effects. The cause for affecting the surface seawater temperature (SST) is from the temperature changing of not only ocean but also atmosphere. That is why El Nino effects and Southern Oscillation effects are combined into ENSO to be studied and researched together. El Nino effect is, however, indicated by SST's over ranging while the Southern oscillation is shown as the vibration of the marine atmospheric pressure. Their indications are different, whereas their effects on climate merge into a single whole.

If SWCR scheme is not realized, urban thermal load does not be taken away immediately by seawater, and the heat would indirectly influence the temperature of seawater. It is the indraught of seawater from subsurface current that reduces urban consumption of electricity and effluence of waste heat. And so, the heat load in the troposphere can be decreased obviously. Currently, it is widely known that El Nino will occur more frequently and more strongly while global circumstance is getting warmer. So, realizing SWCR scheme will certainly weaken the tendency of climate's getting warmer. Of course, its result will not aggravate the intensity of El Nino.

According to meteorological data, El Nino effects were recorded as far back as 1000 years ago, while the industry's scale over the world was too small to cause green-house effect. Of course, the subject of the positive connections between the emergence of El Nino and modern industrialization remain for research. Hence, before we carry out this plan, we need to make clear SWCR scheme's influence during a long-term and short-terms on marine ecotope.

Aside from this, there are still a series of problems should be researched and studied in the earlier stage. Such as:

The influence on ocean's local temperature distribution and flow distribution caused by drawing and discharging a large sum of seawater under different tide, ocean current and various urban regional air-conditioning schemes;

The influence on the energy transmission of using seawater from subsurface current as natural cold resource for urban regional air-conditioning under different tide, ocean current and river current condition;

The SWCR's relevant schemes, including cold seawater's transmission over a long distance, urban air-conditioning's terminal heat exchangers; the amount of seawater's drawing, the number and location of drawing entrances, and distance between drawing entrances and exhaust exits;

Seawater cooling system's retarding corruption, dispersing fouling, killing thalophyte ;

SWCR's parameter optimization and parameter control, SWCR's influence on environment and ecological environment;

Different SWCR schemes' influence on urban local climate, etc.

Only explorations and practices proceed continuously, can human being achieve enormous benefits from the ocean steadily.

#### **References**

1. Wang Minyu, Ma Jie, Wan Manying. *Coupling Model's Numerical Analysis and Calculating on Aquifer's Artificial Thermal Energy Storage*, Energy Technology, Feb. 2004, Vol. 25, No. 4, pp.1-4
2. Geology Society of China, *Marine Geography of China*.. Science Press, Sep. 1996, Beijing
3. Wang Ying, Zhu Dakui. *Coastal Geomorphology*. Beijing: China Higher Education Press, June 1994.
4. A Allonier, M Khalanski, V Camel, *Characterization of Chlorination By-products in Cooling Effluents of Coastal Nuclear Power Stations*, Marine Pollution Bulletin, Dec.1999,Vol. 38, No.12, pp: 1232-1241
5. Hou C., *Seawater Cooling Treatment Technology*. Marine Technology, 2002,Vol.12, No.4, pp:34-40
6. Xu L, Yu Y, Zhou Z, et al.,. *Development of Seawater Utilization Technique in 21 Century, China*, Marine Science, 1999,6(2) ,67-70.
7. Hou C, Wu J, Zhao N, et al.,. *Analysis of and Countermeasures on the Corrosion and Biofouling Deposit in the Seawater Direct Current Cooling System*. Marine technology, 2002, Vol. 20, No. 4, pp:41-45
8. Chen Y, *Several issues about seawater utilization*. Industrial Water Treatment, Jan.2003, Vol. 23, No.1, pp:47-49
9. Xu L, Yu Y, Zhou Z, et al.,. *Development of Seawater Utilization Technique in 21 Century, China*, Marine Science, 1999,6(2) ,67-70.
10. G Fernback, *Seawater plays key role in Stockholm cooling system*, Fuel and Energy Abstracts, Volume 37, Issue 2, March 1996, Page 133
11. Hai X., *Japan Enhance Deep Seawater Utilization Research and Development*. *China Offshore Platform*, Feb. 2000, Vol. 15, No.1, pp:37
12. Ma Jie, Jin Dan., *Urban Integral Air –Conditioning System with Sublayer Seawater as Natural Cold Source*. Patent No. 200410017006.6, State Intellectual Property Office of PRC.
13. Ma Jie, Dai Bin. *Large Amount of Sea Water Pumping System with Variable Depth*, Patent No.200410017007.0, State Intellectual Property Office of PRC.
14. Ma Jie, Jin Dan. *Cold Seawater Purification and Adiabatic Transmission System*. Patent No. 200410017009.X, State Intellectual Property Office of PRC.
15. Kirtman. B. P., J. Shukla, B. Huang, Z. Zhu and E. K. Schneider, 1997: *Multiseasonal prediction with a coupled tropical ocean global atmosphere system*, Mon. Wea. Rev.

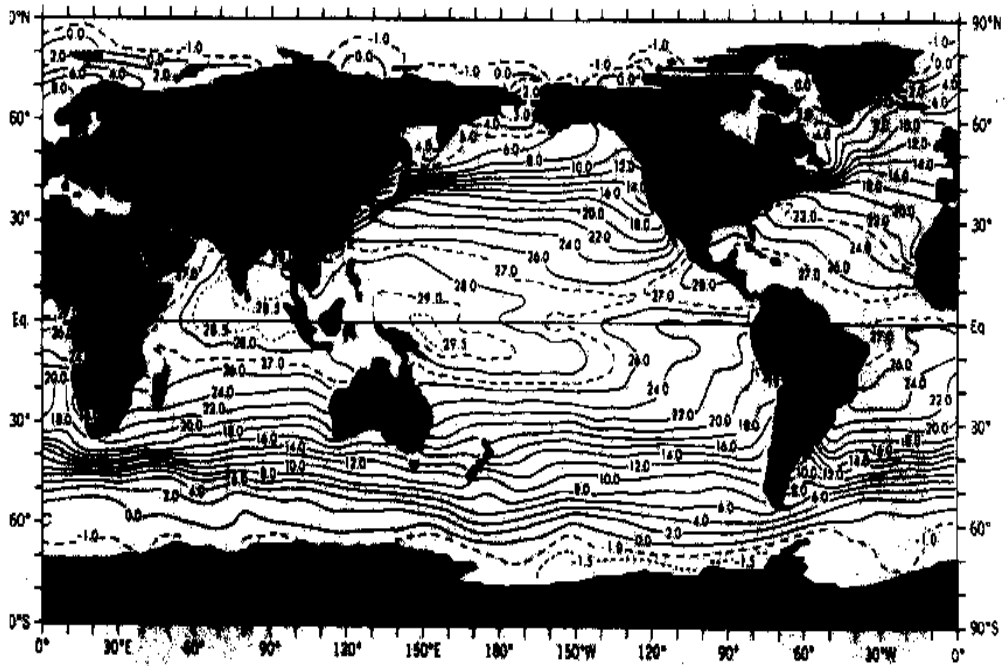


Fig 1 Global sea surface's annual average local temperature

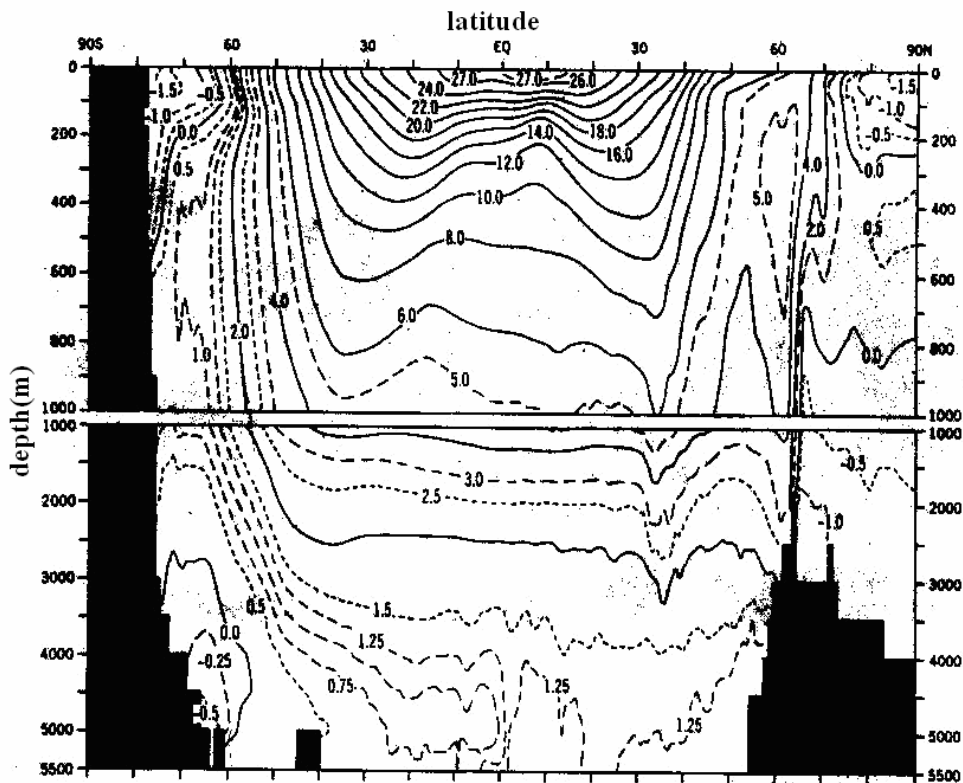


Fig 2 Global ocean's vertical distribution of annual average temperature in latitudinal direction