Energy Rational Use and Underground Space: Opportunities for Sustainability

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ABSTRACT

Cities represent the place where large amounts of energy are consumed: for indoor comfort in buildings, industrial and service activities and mobility for people and goods; some energy sources are also produced (for instance, part of the urban wastes); therefore, infrastructures for energy conversion, storage and distribution are needed.

Underground space plays a significant role either to assure the energy systems operation (natural or manufactured gas pipes, electricity grids, district heating networks, ..), as well as to offer suitable opportunities for every day life (metro systems, storage and parking facilities, road and rail tunnels) through solutions that are more sustainable from the energy and environment point of view than those above ground. In addition to existing underground space utilizations, other innovative opportunities have been recently proposed and some of them became “experimented” case studies (commercial underground malls, leisure centres, multi-utility tunnels, good transportation systems).

Examples of existing and proposed underground space utilizations related to rational energy use are presented and discussed in order to highlight their cost/benefit features.

1. INTRODUCTION

Greenhouse gases emissions and energy demand have risen high on the global environmental agenda. In the last century, the World has seen an uncontrollable rate of urbanisation and a consequent rise in energy demand for private and public consumption and for economic activities, leading on to increasing emissions of GHGs.

This has led to an urgent need for the incorporation of energy rational use issues in urban planning and construction practice: reducing energy demand, choosing suitable sources, improving technology efficiency, mitigating and reducing environmental burdens and impacts produced by urban activities and infrastructures are the main significant challenge, in a context characterised by an high pressure on land use, for urban planners, designers, architects and the local industry managers.

Underground space has been widely exploited since the beginning of the man history and its role is becoming even more important as an alternative, if properly planned, for many functions. In fact, underground space planning and utilization, as well as suitable connections between surface and subsurface developments, can make an increasing contribution to the enhancement of liveability of cities and the improvement of public health, through the multiple use and the reuse of land, the infrastructure development for efficient mass transport systems and provision of services.

Some important aspects of energy efficient urban infrastructure planning and design include the maximising of the energy efficiency of building and infrastructure operations (through the use of renewable resources, decentralised co-generation and energy cascading techniques) with solutions that integrate energy flows and minimise the global environmental impacts, linking also energy and materials producers and consumers to promote resource exchanges and recycling networks.
The solution is the increased use of the underground, appropriately developed and managed: it will provide increased mobility of people, goods and services, improved environmental quality and can solve many problems. The use of the underground is becoming competitive with surface strategies for providing services and facilities. The following paragraphs will describe significant applications related to a) plants and facilities for production, conversion and transportation of primary/secondary energy carriers, and b) solutions for savings in energy end uses.

2. FACILITIES FOR PRODUCTION, CONVERSION AND TRANSPORTATION OF PRIMARY/SECONDARY ENERGY CARRIERS

Outside urban areas, underground siting of medium and large energy plants and related facilities has always been a viable solution for several applications: in-cavern hydro plants, coal gasification facilities (e.g. Belgium), methane recovery and storage systems, stockpiling systems for coal, oil, liquefied petroleum gas and nuclear waste depositories. Urban areas, on the contrary, can host only small and medium size facilities, as far as production and conversion are concerned, but several special uses that support a sustainable urban development (reducing, for instance, the pressure on surface land uses) and allow energy conservation initiatives: energy storage systems, heat pumps, air conditioning and refrigeration equipment and systems for residential, commercial, industrial applications and district heating/cooling infrastructures.

2.1 Energy production plants

Two significant example of underground solutions for energy production plants are the i) heat pump installation in Zurich (Switzerland) and ii) the heating plant in Imola (Italy), both belonging to local district heating schemes.

In Zurich (Figure 1), the heat pump plant is located under a garden, close to the bank of Limmat River (from where the “environmental” heat source is taken) and hosts two heat pumps, heat exchangers and auxiliaries. It has been in use since 1937. The Imola plant (Figure 2), that supplies the local district heating system, is located in the middle of a city park, surrounded by leisure facilities.

2.2 Energy conversion and transportation

Since many years, electricity and natural gas distribution systems are usually located under city streets; in cold and temperate climate regions, also district heating networks are laid underground; district cooling systems start to compete with the previous ones. Cables, pipes and auxiliaries constitute very complex systems, that frequently interfere, as far as their management and development are concerned. Sometimes, very critical conditions are reached, with a resulting lack of safety, in addition to relevant economic penalties.

Traditional planning techniques are mainly focused on two-dimensional representations of regions and urban areas. This approach is generally adequate for surface and aboveground construction, but not for...
structures in underground. Subsurface planning must be an integral part of land use planning processes. National, regional and local policies should be developed in order to provide guidelines, criteria and classifications for assessing appropriate uses of underground space. The need of an underground urbanism, as an implementation of the traditional urban planning approach, is starting to promote new technical solutions (e.g. multi utility tunnels for energy network systems) and regulations (e.g. Master Plans for Underground Services).

The following figures 3, 4 and 5 show some multi-utility tunnel examples in Geneva, Stockholm and Copenhagen, where energy networks (electricity grids and district heating pipes) are located with TLC cables and water supply services. The advantages for operation, maintenance and safety are evident.

Fig. 3. Geneva (Rues Basses) Tunnel.

Fig. 4. Stockholm tunnel

Fig. 5. Copenhagen tunnel works and shape.

2.3 Thermal energy storage

Today, there are several applications in various countries of Underground Thermal Energy Storage systems (UTES), which started to be developed in the 70’s with the purpose of energy conservation – accumulation of thermal (cold or warm) energy to be used in different time (or season) - and for a more efficient utilization of energy resources, including renewable ones (that need storage, since are strongly time dependent).

The ground has the capacity to store thermal energy over long periods for seasonal management: the technical solutions are very robust and simple (Figure 6). The main thermal energy storage in the underground methods are i) storage in pits, tanks and rock caverns, ii) storage in aquifers (Aquifer Thermal Energy Storage - ATES) and iii) storage in ducts (Duct Thermal Energy Storage - DTES) systems.

Fig. 6. Seasonal thermal energy storage.
UTES represents one of the most sustainable and environmentally friendly approaches, with great future potential: it saves power, reduces the size of distribution units and hence lowers the cost and environmental impact of energy systems. In addition to storage applications, underground itself can play the role of a direct energy source, like in heat pump installations using the heat content of groundwater or soil (Figure 7), or when an high temperature gradient allows the exploitation of geothermal energy.

![Fig. 7. Heat pump systems in commercial or residential applications.](image)

3. SOLUTIONS FOR SAVINGS IN ENERGY END USES

Energy saving solutions in end uses involve the allocation in the underground space of activities with, sometimes, a relevant reduction of primary energy consumptions, due to

- higher thermal insulation, in comparison with external buildings
- better efficiency of the installations, like for passenger and goods transportation systems, because they do not interfere with other surface traffic modes.

Moving infrastructures to underground, moreover, results in a relevant contribution to the achievement of higher sustainability and liveability in overcrowded and congested today cities.

Examples of such solutions are presented in the following paragraph: public spaces in the Underground City of Montréal and at the Shanghai Shopping Mall and an innovative application of an “old” technology: the Pneumatic Capsule Pipeline infrastructure for freight transportation.

3.1 Montréal and Shanghai: examples of Public Underground Space

In “underground cities”, a network of tunnels usually connects buildings in downtown areas: office blocks, sport facilities, shopping malls, train and metro stations, theatres and other attractions. It can usually be accessed through the public space of any of the buildings connecting to it and sometimes has separate entries as well.

The most famous underground city in the world is Montréal: with over 32 km of tunnels spread over an area of twelve square kilometres, the 60 residential and commercial complexes comprise 3.6 square kilometres of floor space, including 80% of all office space and 35% of all commercial space in downtown Montréal (Figure 8, 9). Services include shopping malls, hotels, banks, offices, museums, universities, seven metro stations, two commuter train stations, a bus terminal and the Bell Centre. There are more than 120 exterior access points to the underground city. Some 500,000 people use the underground city every day (especially to escape the traffic).

This underground city is also an important tourist attraction, promoted by Montréal travel guidebooks, and a good practice of underground urbanism in city planning sector.
During the last decades, we have also seen the development, in the underground space, of shopping malls and centres (one or more buildings that contain stores), with interconnecting walkways enabling visitors to easily walk from store to store. Many consumers prefer malls, with their large parking garages, well-maintained walkways and private security guards, over public streets, which often suffer from limited parking possibilities, poor maintenance and limited police control.

Among the most recent projects, Shanghai City is planning to grow more plants in subway stations and underground shopping malls by 2010 to improve the scenery and purify the air. The idea is being studied by researchers at Tongji University and is expected to be implemented in an underground facility within the 5.28-square-kilometer World Expo site between Lupu and Nanpu bridges.

3.1 Pneumatic Capsule Pipeline: an old technology for new applications

PCP is the transport of materials or goods by capsules propelled by air moving through pipeline. Great advancement in PCP technology has taken place in the last 30 years in Japan, where PCPs have been successfully used for transporting minerals, construction materials and solid wastes. Underground space utilizations often require tunnelling and excavation, in which large quantities of materials need to be transported during construction. The use of PCP to transport such materials offers many advantages, including low cost, greater construction safety and reduction of air pollution in tunnels.

Using capsules with steel wheels rolling inside steel rails has many advantages: energy conservation, reduction of maintenance cost, easy control and higher speed without damage to wheels. These solutions, reducing the number of vehicles moving on the streets, reduce air pollution, noise and...
accidents generated by trucks; increase safety and security; assure more rapid and reliable delivery of goods; require less energy use and reduce the dependence on imported oil. There are many other potential applications of the modern PCP technology into large cities, such as for solid waste transportation, delivery of pallet goods and dispatch of containers from and to harbours. Cities will benefit in many ways, including reduction of traffic jams, accidents, air pollution and noise caused by trucks.

4. CONCLUSIONS

The underground space represents a viable opportunity to develop rational energy use schemes and to improve the urban sustainability, offering the most suitable sites for energy plants and infrastructures, as well as solutions for saving energy and solving (or reducing) the burdens produced by urban activities (in mobility, trade, leisure and so on).

The two following figures associate an old vision of a “Rue Future” in Paris (Hénard, 1908), with a clairvoyant utilisation of underground space utilisation, and a present day vision, in Japan (1998), at a district level.

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**Fig. 13. Hénard’s Rue Future (1908).**  
**Fig. 14. Present day Vision in Japan presented at World Energy Council Conference in Houston (1998).**

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