Reduction of the Energy Peak Demand in Buildings by PCMs

El Hadi Bouguerra
Saad Dahlab University
Algeria

Abstract: To avoid or at least to attenuate the global warming, it is essential to reduce the energy consumption of the buildings where the biggest potential of savings exists. The impending danger can come from the increase in the needs of air conditioning not only because of the climate warming but also the fast equipping of emerging or developing countries. The problem of simultaneous energy needs in summer put a lot of stress on the grid with a blackout risks and leads to oversize the electric producing facilities. Using phase change materials (PCM) as an artificial thermal mass can reduce the cooling energy demand or at least delay the peak demand. Even if PCMs do not always avoid the resort to an active cooling (mechanical), they allow lowering the load at an acceptable level which can be possibly taken in relay by the renewable energies. These solutions have the advantage to be relatively less expensive and especially adaptable to the existing housing.

Keywords: Low energy building, Energy conservation, Peak demand, CO₂ reduction.

I. INTRODUCTION

In its reference scenario of worldwide energy policy preservation, the International Energy Agency (IEA) has foreseen in 2011 that the 2035 energy demand could exceed by 35% the level of the current demand. The hydrocarbons part exceeds 60% in this increase. Even in the event where the consumer countries would apply more vigorous policies of alternatives energies to settle the worrisome questions of environment and energy security, the increase at the horizon 2035 should anyhow be 30%, i.e. an annual increase of 1.6%.

Developing countries are responsible for 90% of the increase (among which 45% for China and India) in a way that they will represent more than 50% of the world energy demand in 2035 [1]. The major part of this increasing demand is for electricity mainly produced by the coal-based power plants, which emits 70% CO₂ more than the gas ones for example. For example, in 2002, 40% of the CO₂ emissions were due to electricity generation [2]. The global warming being essentially due to the fossil fuel, a priority action must be taken for electricity consumption caused by the increased use of air conditioning actually affordable even for low income persons.

II. ENERGY CONTEXT IN THE BUILDING

We can consider roughly speaking that the energy demand in the world fall into approximately 1/3 for the building, 1/3 for the industry/agriculture and 1/3 for the transport. For the transport, the potential savings are low. The research/development is only eroding the consumption and the few gained savings are widely balanced by the increase of the vehicle fleets, because emerging countries tend to catch up with developed ones. There is also a continuous growth of the air and maritime transportation because the intensification of exchanges due to the globalization of economy. For the industry, there is a real potential but the mutation remains expensive and slow especially with the greater world competition. A great effort was already done in energy conservation especially in developed countries. Anyway, hydrocarbon fuel can hardly be substituted for these two sectors and will remain the main source of energy for long time to come.

Remain the huge potential of the building since approximately 70% of this demand concerns the heating/air conditioning. For example in USA, the energy consumption of the new houses can be reduced by 50% without practically any supplementary cost only by adopting a new concept of construction (NREL). On the average, every German low energy building ‘Passivhaus’ saves up 80% on the heating energy and so avoids 2.4 tons of CO₂ emission a year [3].

For the new buildings, the actual target is to reach by 2050 a quasi-null fossil energy consumption with the needs reduced by about 70% and consequently, the renewable energy contributing by 30% (Zero energy concept). Indeed, by keeping the current building consumption, substituting fossil fuels by renewable energies is technically practicable but economically illusory. Reducing energy consumptions is giving a chance of success to the renewable energies [4].

In their best hypothesis, the IPCC (Intergovernmental Panel on Climate Change) has estimated that to limit the earth average temperature increase to a maximum of 2,4°C, the rate of greenhouse gases (in particular CO₂) should be brought back down to between 50 to 80% of their level before 2000.
But more than a half of 2050's buildings are already built with a little or null energy preoccupation. Assuming a yearly housing park renewal rate ranging from 0.1 to 0.5% (developed countries rate), 200 to 1000 years would be needed to replace the current park of buildings... To fulfill the 2050's objectives of CO₂ reduction for Kyoto, it requires besides the transition to low energy of all the new housing which will be built in the meantime, but also necessarily the renovation of the existing sector at the rate of 2 to 5% a year. This can present enormous problems of costs and implementation with the actual urban constraints.

III LOW ENERGY BUILDING AND HOT CLIMATES

Houses with very low energy consumption meet some success because the technical solutions can be easily integrated into the houses that are built today. There is no significant difference as regards the aesthetics, the room’s arrangement or the methods of construction. They are accepted well by the households and the promoters.

To reach this target of low energy buildings, three axes of intervention must be followed:

1.-Reduction of the energy consumption: by the constructive systems, the insulation of the opaque walls and the treatment of the transparent walls (windows).

2.-Use of renewable energies, PV (photovoltaic) electricity, combined heating-warm water solar systems, heat storage, micro-network heat etc.

3.-Efficient use of the fossil energy, double ventilation with heat recovery, compact HVAC systems, micro-cogeneration, low consumption refreshment etc.

In 2011, estimate gave 92 millions/year of air conditioning units sold mainly RAC (Room Air Conditioner) with an annual average increase of 13% over the 2006/2011 period. Demand is expected to double between 2011 and 2020 especially in emergent countries [7].

Globalization makes that these equipments formerly reserved only for the service sector are now relatively low cost and accessible to the residential sector even in countries with low income. Unfortunately, their energy efficiency is often proportional to their prices.

Fig 1. Energy reduction demand is the most important step toward a sustainable energy [5].

Whatever is the model used, any action goes necessarily through an important reduction of the energy demand in the housing. Figure 1 and Figure 2 are perfect didactic examples.

Fig 2. Energy performances of buildings [6].

Assuming an average of 1 kW power unit and even in the case of a partial operating, it is the equivalent of a dozen of the most powerful power plants that it is necessary to build every year only to satisfy this supplementary peak demand. It is important then to find the means to reduce or at least shave the electric peak demand since air conditioners mainly use electricity. Those problems of simultaneous energy needs in summer put a lot of stress on the grid with a blackout risks.

For the Mediterranean warm to hot climate countries, the problem of summer comfort can become essential. The basics of low energy building design such Passivhaus or Minergie labels developed for cold countries must be modified to take into account the most important contribution of solar irradiation. This heat contribution reduces the thermal loads in winter but increases presently the problems of summer overheating. This aspect is particularly important because due to the endemic crisis of housing in many Mediterranean countries, buildings were built without any preoccupation with energy. However, with the actual development of the human comfort, these buildings are now equipped with air-conditioning and become very voracious consumers on electrical energy what lead to a boom on demand in the summer period.
IV PHASE CHANGE MATERIALS IN BUILDINGS

If some well known passive techniques have shown a real efficiency in the reduction of the energy needs of the new buildings where they were integrated from the design and the construction, it is not the same case for the existing housing where these passive practices are rarely applicable. For example, a thermal insulation to be really efficient must be made on the outside of the house envelope. This is impractical in buildings already integrated into the urban architecture. It's the same for the thermal mass, the permanent solar protections or the orientation of the housing that are generally an inheritance of several decades of urban development. But recent improvements on some techniques well known by the past but suffering from some inconveniences, make them very promising especially on the adaptation to the existing housing.

For example, in buildings, thermal mass can be used to store energy and attenuate indoor temperature fluctuations. By minimizing deviations from the comfortable temperature range, the need for energy intensive heating and air conditioning can be significantly reduced. But to have to have an interesting time lag (see figure 3), about some hours until the outdoor temperature goes down appreciably, important thickness of walls are needed, that is hardly and economically practicable especially in the collective or existing housing. The advantages of a thermally massive building often conflict with practical considerations in the design process. Aesthetics and cost pressure often require modern buildings to be increasingly lightweight. A solution can be the introduction of phase change materials (PCM) in building construction materials as a kind of an artificial thermal inertia.

![Diagram of temperature evolution by thermal mass](image)

Fig 3. Example of evolution of temperature by thermal mass.

The main issue with energy conservation is often the heat storage. Thermal storage could either take the form of sensible heat storage or latent heat. Latent heat storage is accomplished by changing a material's physical state whereas sensible storage is accomplished by increasing a material's temperature. To store the same quantity of energy smaller quantities of material are required for latent storage. This could be illustrated by using a common building material such as concrete, which has a sensible heat capacity for approximately 1.0 kJ/kg whereas a phase change material (PCM) such as calcium chloride hexa-hydrate can store/release 193 kJ/kg of heat on phase transition [8]. A further advantage of latent is that heat storage and delivery occur at a constant temperature. An exhaustive review on PCMs characterization and their applicability to various devices and heating/cooling systems can be found in the literature [9].

The order-of-magnitude in the increase in thermal storage capacity for PCMs and their almost isothermal discharge allows the storage of high amounts of energy without significantly changing the temperature of the room envelope. This effect could be exploited to stabilize ambient temperatures inside buildings. Melting temperatures must be in range that is relevant to housing requirements.

Solutions that increase the thermal mass of a building without increasing the structural weight are therefore particularly desirable. Incorporating PCM in buildings is a mean to increase artificially thermal mass of lightweight structures [10] and [11].

The walls and ceilings of a building offer a large area for passive heat transfer storage within every zone of the building. So, incorporating PCM in building material like gyspum wallboards, plaster, concrete to increase the thermal mass seems to be an interesting idea. The manufacturing of phase change material PCM implemented in gyspum boards, plaster or other wall-covering material would permit the thermal storage to become part of the building structure. As heat storage takes place inside the building, where the load occurs, rather than externally, additional energy transport is not required [12].

Phase change materials have to be accessible from the rooms and the molten PCM must not soak construction materials. Therefore, they need some form of containerization to be used for thermal storage in buildings. Encapsulation is a containment method for PCM to avoid leakage or reacting with materials matrix. Several proposed systems encapsulate the PCM in tubes, pouches or spheres. The drawback of this method is the poor heat transfer rate due to the low conductivities: freeze is only near the interface.

Actually, the available commercial micro encapsulated PCMs are made with paraffin waxes embedded within small polymer spheres, about 10-20 μm in diameter. These are then mixed directly into the building material or facing wallboards. Significant PCM mass fractions, up to 30%, are achievable. The PCM is chosen to melt in the working temperature range of the thermal mass. The additional latent heat capacity for the distributed PCM increases the overall effective heat capacity compared with sensible storage alone, potentially allowing improved temperature attenuation from a smaller amount of the thermal mass [13].
The micro-encapsulation in small spheres increases also heat transfer area since the surface to volume ratio increase [14], reducing the PCM reactivity towards the outside environment and controlling the change in the storage material volume as phase change occurs. Further, plastic encapsulation is safe as PCM is not in direct contact with the material. Incorporating PCM in gypsum plaster or gypsum wallboards has the advantage of great heat transfer surfaces in direct contact with the indoor temperature and avoids interfering with the structural strength of buildings. As the interior lining is usually made with multilayer gypsum plaster, PCM can be easily added to the plaster and installed both in new constructions and during the rehabilitation process of existing buildings with no additional cost (except for the material).

Heat latent wallboards panels are now commercially manufactured and are constituted by a mixture of gypsum and encapsulated PCM (26%). With only 15 mm thickness, they can store up to 330 kJ/m² of heat at temperatures switch between 23 and 26°C and are equivalent to a 9 cm thickness concrete wall or 12 cm bricks wall on energy storage capacity.

![Graph](image)

Fig 4. Cooling energy demand with and without PCM in some Mediterranean cities [15]

Dynamical modeling of a typical residential building of about 100 m² was done in different warm climates Mediterranean cities [15]. Results have shown that it is possible to have a peak shaving of 3 to 5°C on the extreme temperatures of rooms equipped with PCM what allows to limit the appeal to the systems of air conditioning for several days in the year. As shown in figure 4, about 20% of reduction was also observed on the demand of air conditioning.

It is nevertheless necessary to choose the phase change temperature (and thus the material) such that the PCM passes on both sides of this temperature and can accomplish the whole cycle of load release heat otherwise it would be have a classical material behavior. Indeed, the PCM is only storing the heat, it does not move it. So it would be necessary to insure a night-ventilation to evacuate the heat stored to ‘empty’ the PCM for the following day [16]. This characteristic can become very important in the service sector where the daily occupation is only partial. The PCM stores heat during the day when offices are occupied and release it later when they are vacant. It is sometimes enough to move only for some hours the peak of temperature which is generally in the afternoon till the end working schedules to save a big part of the total cooling energy.

Those encapsulated PCMs can be easily implemented into existing housing as walls coatings. They can delay the consumption peaks of the electrical energy and reduce the demand of power during the rush hours by moving it towards slack periods. Numerous countries encourage this by setting differentiated hourly electric prices.

V CONCLUSION

The increasing demand of air conditioning especially in developing countries is a time bomb for the global climate warming. The supplementary electrical energy demand is on the way to be satisfied by means of CO₂ emissive energy sources mainly fossil.

The phase change materials can be used to decrease the energy loads or at least shave the peak energy demand and it can be done for a low additional cost especially if it is implemented at the construction initial design stage. A reduction of about 3°C on peak temperature is obtained that permit to avoid using mechanical air conditioning many days in the year and a reduction of about 20% of annual cooling energy in warm climates.

In fact, the reduction of the energy consumption remains the best mean to limit the resort to fossil fuels and make economically viable the use of the renewable energies. It also gives time to the research in this field to succeed and to reach the phase of industrial maturation.

REFERENCES


