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Traditional Energy – Free Solutions for Ventilation and Air-Cooling in Arid Tropical Areas of Asia

Abstract

Nowadays, more and more air-conditioning devices are installed to cool the inner spaces of dwelling houses and public buildings in the populous developing countries, mainly—within Asia—in India and in China. The need for such devices contributes not only to the growth of municipal and public electricity consumption and emission of pollutants, but it is also responsible for a negative self-generating process: the more greenhouse gases are released—as a result of air-conditioning—the warmer our environment becomes. Therefore, it is worth drawing attention to those traditional methods and architectural forms by which comfortable air conditions could be generated in the hot arid and semi-arid areas of our Planet—with respect to this study in South Asia. We can find several examples of such solutions in India and in the Iranian Basin, as well. Modern age architects have also started to discover the importance of these ancient methods and to apply them in their works. Although, widespread use of such techniques cannot be expected in the near future, the success of these innovative but low-key attempts achieved until now should be reported.

Key words

Air conditioning; Air pollution; Developing countries; Traditional air comfort improving; Traditional methods of architecture

1. The environmental and social effects of the spreading of air-conditioners

The serious consequences of the increasing rate of industrial and energy production, motorisation and, closely related to them, population growth and urbanisation—such as the negative climate changing effects of greenhouse gases accumulated in the atmosphere—have gained scientific certification in the last fifty years. The spreading of electric air-conditioning contributes greatly to the environmental damage occurring in the form of air-pollution through the emission of various gases in energy production or directly from the AC devices; although, this fact hardly has any impact on social awareness. The increasing need for these devices is well-marked by the turnover growth in the market of air conditioners that reached 13% between 2010 and 2011. Meanwhile, the amount of energy consumed by air conditioners put into the electrical system was 10^{12} kWh/year (COX, S. 2012). The total energy demand of air-conditioning is naturally enhanced by the AC equipment of motor-vehicles through their excessive fuel consumption.

It should be noted that global as well as regional aspects of the year by year observable consumption growth are conspicuous, as we have recently witnessed a remarkable spatial rearrangement in this regard, too. Nowadays, the "leading" role of the *United States of America* is still undoubted regarding both the number and energy consumption of air conditioners put in operation. Moreover, the amount of electricity used for air-cooling is higher than the whole current consumption of *Africa*; between the years of 1993 and 2005, this kind of current use had doubled, until 2010 it increased by 20%, moreover—and as a result of additional energy need of vehicles and buildings—almost 500 million tons more CO_2 has been emitted into the atmosphere (COX, S. 2012). However, the advance of economically developing countries with high population is more and more evident in this field, as well. Among them is *China* where only in 2010 50 million air conditioners were sold. According to the unanimous belief of forecasts, the number of climatised vehicles will have doubled by 2015, reaching 100 million. Furthermore, by 2020 preceding the *USA*, *China* will have become the first ranked in the use of electricity for air-cooling purposes (Cox, S. 2010), thus, by 2050 *China* will have been the most dominant state in current consumption for climatisation which, according to long-term prognoses, will have risen tenfold on global level by that time (Isaac, M. – Vuuren, D. P. 2009). Considering the future, it is more and more certain that, simultaneously with the overstocking of the local market, the developing, first of all *South* and *Southeast Asian* countries—of which India already excels—following *China* in the development of economy and in the rise of living standards with some time lag will be the great consumers of the post-2020 period (McNeil, M. A. – Letschert, V. E. 2008). The increasing demand for air conditioners in *India* has more reasons. On the one hand, it is a means indicating the status symbol of the vigorously expanding and strengthening middle class; on the other hand, there are also real needs for AC devices because of the higher indoor temperatures as a result of the new architectural design and building materials. The latters have replaced the traditional ones which have been adapted to the local climatic characteristics. It is supported by the data according to which the turnover of AC equipment has increased by 17% in the last three years in *India* (Dahl, R. 2013).

In connection with the environmental and economic effects of the spreading of AC devices, some geographical relations worsening the problem should also be pointed out. First of all, the economically developing countries are partly the most characteristic scenes of urbanisation and are predominantly situated in the tropical–subtropical regions of the *Earth*. It is convincingly demonstrated by the fact according to which 37 out of the world's 50 most populous agglomerations—among them 14 are in *China* and in *India*—can be found in the developing world and the ones with the hottest climate (30 out of 50) with the exception of 3—having their CDD (Cooling Degree Days) index higher than 1000—are also located in this group of states (Sivak, M. 2009), based on the country classifying system of the *International Monetary Fund* (IMF Online 2012). The CDD index is such a product of multiplication which is applied to express the rate of need for air conditioning, and one of its parts is the sum of the number of days with more than 18°C (64.4°F) mean temperature, while the other part is constituted by adding up the value domain of each day's mean temperature exceeding 18°C (64.4°F).

Considering the environmental effects of the spreading of electric climatisation, the type of the primary energy resources applied to generate electricity is not negligible either. In this regard, we should also take into account the spatial features of the types of fossil fuels and their roles in energy production, as they contribute significantly to the increase of exhaust emissions, but in a different degree. The difference between the material characteristics of coals and hydrocarbons—especially that during the oxidation of the latter, the amount of carbon gases emitted is fewer—has a well perceptible impact on environmental degradation. This rise becomes particularly significant if *China* and *India* are picked out of the group of developing countries on the basis of their population and economic potential as well as their climatic characteristics. In these two countries, about $^2/_3$ of the electricity is generated in coal-fired power stations (Probáld, F. 2008; Szegedi, N. – Wilhelm, Z. 2008).

As a result of the growing need for air cooling, more and more greenhouse gases are released into the atmosphere which, in connection to global warming, starts a self-generating process that increases the amount of electricity used for climatisation of buildings and the rate of air pollution onwards. The decrease of energy needed for heating, which is mainly based on hydrocarbons, is unable to compensate for the strengthening of this environmental impact. The population growth and the improvement of income conditions of the developing world have considerably contributed to this, as well. On the other hand, this also means that the cumulated energy need and greenhouse effect of heating and cooling is going to increase further in the coming decades (Isaac, M. – Vuuren, D. P. 2009).

The increased demand for electricity—the degree of which is well demonstrated by the 2.0–2.5-fold rise of electrical energy used in the hottest months in *Delhi* between 2000 and 2009—is endangering, not only the environment but also the safe industrial and public power supply (WOLFRAM, C. 2012). For instance, *India* suffers from a day-to-day lack of energy in some places and times. Even 16-hour long power cuts can happen (COX, S. 2012) with which AC devices contribute to increasingly burdening the electrical grid.

2. Possible solutions to mitigate the environmental impact of air conditioning

If we wish to insist on the present habitual air-comfort level of cooled interior rooms also in the future and we would like to assure the cooling of inner spaces by air conditioners solely, there are theoretically two possible ways of solution strengthening each other's effect to keep back the concentration growth of greenhouse gases emitted into the atmosphere. One of them is to increase the energy efficiency of the devices and the other one would be the larger scale use of renewable energy resources.

The success of attempts to increase efficiency depends on the development and spreading of the optimum refrigerant of AC devices. In the most widely used and presently operating air conditioners, hydrocarbon derivatives pertaining to *Hydrofluorocarbons* (HFCs) are the materials applied as refrigerants in the cooling cycle. These were bound to replace the refrigerants of the older equipment namely *Chlorofluorocarbons* or *Freon* (CFCs, HCFCs) depleting the stratospheric ozone layer, after the so-called *Montreal Protocol*. The latter is an international agreement that constrains their production and circulation of them which came into force in 1989. Although, the decreasing process of the ozone layer concentration has been managed to stop and even reversed, the greenhouse effect of these chemicals (both the CFCs and the HCFCs) is still considered as a huge problem. When comparing the GWP (Global Warming Potential) of these hydrocarbon derivatives with that of CO_2, the former can be greater by 2–3 orders of magnitude. Their role in global warming is less significant than that of other greenhouse gases, but only because they are released in much lower concentrations into the atmosphere.

In the spotlight of these facts, it is undoubted that the key factor in the modernisation of AC devices is the replacement of old refrigerants by new ones with much lower GWP. But it seems that such an attempt will not lead to real solutions in a short term. With the increase of efficiency also in view, their technical efficiency is much lower than that of HFCs, not to mention their other problematic characteristics like inflammability, toxicity, ozone depleting effect and so on. Besides, the positive environmental impact of some possible improvements in energy efficiency would not prevail because of the increase in the CO_2 emissions as a result of the energy need for operating the more and more newly installed air conditioners (COX, S. 2010).

Optimistic and scientifically grounded analyses as well as scenarios regarding the future role of renewable resources in the process of energy production, like the Energy Report which has been made in the cooperation with *WWF* and *Ecofys* and was completed in 2011, slip out practically every day. Accordingly, it is possible that renewable energy resources could meet the energy demand of the *Earth's* whole population by 2050 (SINGER, S. ed. 2011). However, because of the real environmental risks and cost effectiveness problems, we cannot trust in the significant advance in this field in the near future, that is in the more efficient exploitation of the potential reserves lying in renewable energy sources. Consequently, in a short term at least, the amount of electrical energy coming from this kind of resources—approximately 750 billion kWh/year in the present time—will not increase notably.

In the spotlight of the above mentioned facts, putting a stop to the endless spreading of mechanised air cooling should really weigh up the possibility of making way for traditional, mainly free methods based on shading, ventilation and airing by means of which tangible results can be achieved in the reduction of air pollution level and relieving of energy dependency. This is not a doomed enterprise. The suppositions of scientific studies or surveys, according to which in spaces where continuous air movement by natural or artificial ventilation is ensured and the occupants of rooms are protected against the direct influence of sunlight anyway, the temperature tolerance limits are shown to increase and seem to be justified (Busch, J. F. 1992; Brager, G. S. – Dear, R. 2001).

3. Air comfort sense improving traditional architectural methods in India and in Iran

It is not a new recognition at all that in the arid and semi-arid climate areas of *Northwestern India* and the *Iranian Basin*, for instance, we can witness many long established technical methods which are also justified in the modern architecture. These methods help adapt to extreme weather conditions by the use of cooling and heat extraction potential of water, capitalising on the opportunities of shading techniques, strengthening the intensity of natural air movement as well as building and space shaping technologies adjusting to the thermal absorbing and radiative capacities of building materials.

Typical examples of utilising water for this kind of purpose are the stepwells, serving as public spaces. They are spread in the hottest and driest northwestern parts of the *Indian subcontinent*. Stepwells granted refuge from the heat not only to the local population, but—since these were often built along the major trade and military routes, too—as halting places and bases for replenishment of water resources, they also ensured refreshment for travellers (Wilhelm, Z. *et al.* 2008). Depending on language areas, these water sources are called *baori*, *baoli*, *baodi* or *vav*, *vaav*, *vavdi*. The water basins come to light in the towns of the *Indus Valley Civilisation*, the range of which is very comparable to that of stepwells today offer themselves spontaneously as the historical prefiguration of the baoris being formally similar to them. Nevertheless, the first typical well constructions used mainly for public purposes appeared only about in the middle of the first millennium CE in *Gujarat*. From here on, they were gradually gaining ground northward, in *Rajasthan (Figure 1)*, as well (Livingston, M. 2002).

The baoris could be utilised in various ways: they combined the functions of simple wells and masonry basins, i.e. water tanks being common in *India*, too. As round, square or polygonal-formed structures recessed as far down as the ground water level also enabled to store the rain water falling in a modest amount during the wet season. In some cases, the occasionally covered stepwells are tens of meters deep and have hundreds of square metres basic area. They consist of several

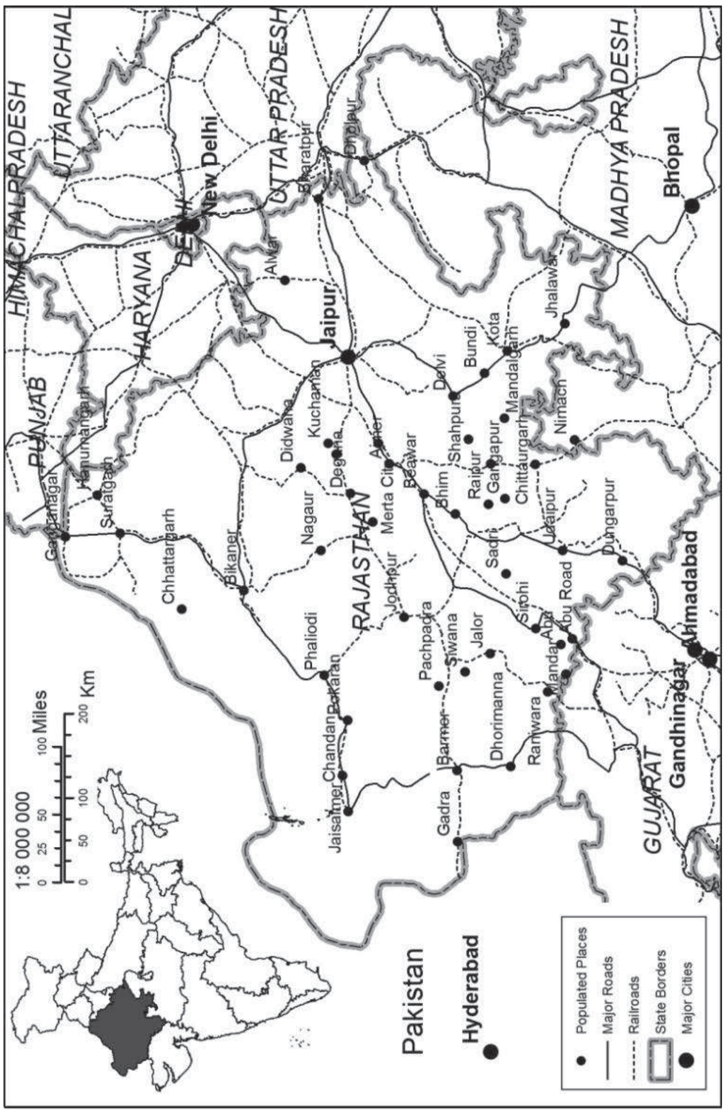

Figure 1 – Rajasthan in India
Edited by Szelesi, T. (2013)

stages among which steps running around the side walls or in the galleries provided interconnection to the water basin.

The steps—which either got under the water or emerged from it, depending on the fluctuation of the water level—ensured the approach of the actual water surface. The stepwells were suitable not only for providing continuous water supply, but these deep well buildings put up of thick stone blocks and storing a relatively big and cold water mass were pleasantly cool scenes for communal gatherings, as well. Additionally, as a result of the special cultic designation of water, they were supplemented by sacred roles, too, serving even in our days as sacrificial places of locally revered deities. One of the oldest and largest stepwells in *India* is the 20 metres deep and 13-storey high *Chand Baori* built during the 8–9th century CE in *Eastern Rajasthan*, which—even lacking its original functions—can be regarded as the model of a space formation adapting to climatic conditions *(Figure 2)*.

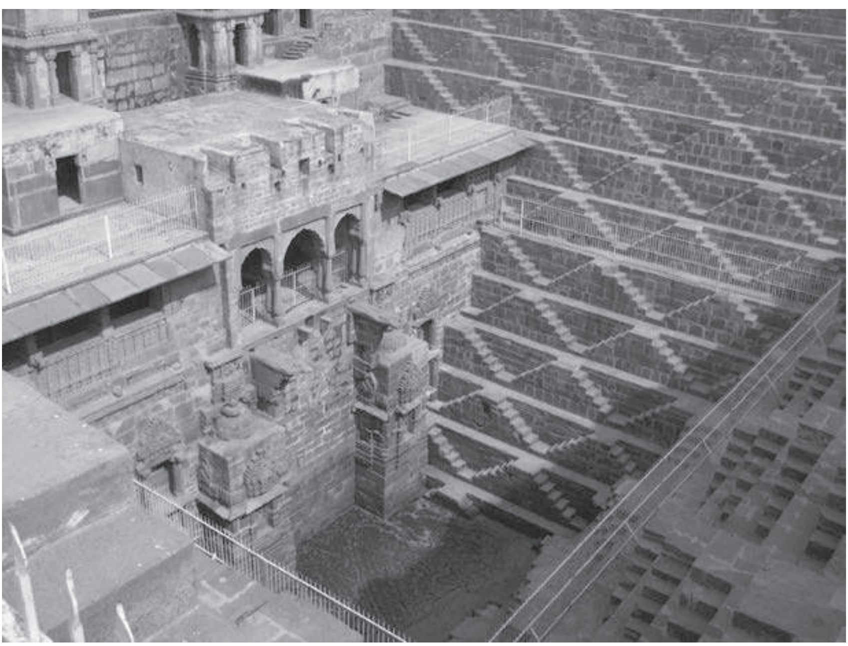

Figure 2 – Chand Baori, stepwell in Abhaneri village, Rajasthan
Photographed by Zagyi, N. (2012)

In relation to natural aeration, we ought not to forget about the architectural impacts of baoris marks of which are most evident among royal residences built in *Rajasthan* during the 17–18th centuries. In the case of these palaces enriched by *Mughal* stylistic details and placed next to water tanks or even gradually protruded into them, it was a generally established custom to apply such kind of structural and frontal elements by which the air temperature mitigating effect of water could be exploited. We can come upon maybe the most prominent examples of this in a small town named *Deeg*, near *Bharatpur*, on the annexes and pavilions of the local palace complex built by *Suraj Mal maharaja* in the 1730s which looks to and is partly situated above a water tank *(Figure 3)*.

Figure 3 – Gopal Bhawan, Suraj Mal's summer residence, Deeg Palace
Photographed by Zagyi, N. (2012)

The natural air comfort enhancing techniques could be applied successfully not only in case of isolated structures, but they could also have a favourable influence on the climatic conditions of entire cities. In this regard, it counts as a key element to plan and form such kind of a layout which adapts to the changing angle of incidence of rays during the day. That means the correct orientation of road network and the right choice of the streets' width (GUPTA, V. 1985). The slightly wider lanes serving for through traffic are led in an east–west direction, whereas the far narrower passage-like joining streets are perpendicular to them, minimising the effect of direct radiation reaching the building surfaces and the streets encircled by them. In addition, the houses were built next to each other and face to face as closely as possible. The private balconies of the upper floors protruding from the street front wall-faces also increased the shadowing of the spaces between the houses. Besides window panes, the so-called jalis were also utilised to reduce interior air temperature. They are in fact *Sun's* rays breaking reticulated pierced stone slabs forming geometric or plant shapes and are widespread in the *Mughal* and *Rajput* architecture. The jalis are fit not only for screening, but they also substitute masterfully for the three functions of windows: they provide view, ventilation and light transmission at the same time (GUPTA, V. 1984). Furthermore, the jalis have gained such a vast popularity as impressive frontal decorative elements that important late medieval public and private buildings in *India* would have been inconceivable without applying this typical ornamental motif. In addition to a great number of other works, the artistically sculpted details of the *Amber Fort* built by *Raja Man Singh I* near *Jaipur* at the end of the 16th century; among them the wall-faces of the *Ganesh Pole (Ganesh Gate)* preserve a splendid memory of this *(Figure 4)*.

Another efficient way of reducing the temperature sensation is the air-flow routing by means of the so-called courtyard effect on the settlements that have been adapted to the tropical climatic conditions by applying traditional layout and building methods indicated above (GUPTA, V. 1981). Beyond the close location of the street façades, it was made possible by forming relatively spacious courtyards among the wings. Its operating mechanism is based on the physical properties of

Figure 4 – Jalis on the Ganesh Pole, Amber Fort, Rajasthan
Photographed by ZAGYI, N. (2012)

the air maintaining the general circulation, that is its density changes depending on increasing or decreasing temperature, and it moves from a lower pressure towards a higher pressure one. Accordingly, the cooler and heavier air mass of the narrow well-shaded streets sinks, but the less dense air of the courtyards warmed by the direct radiation carries out an upward motion. From the point of view of the natural ventilation of the building interiors, the most important circumstance is that during the pressure equalisation the air getting in from the street through the loose textured front faces of the upper floors reticulated by jalis and crossing the residential spaces towards the courtyard creates transversal draught. The temperature of the inner courtyards and premises adjacent to them could be reduced by evaporation where financial opportunities as well as sufficient water resources were available to realise it. The cooling effect of water of fountains and shallow basins as well as channels existing in the inner courtyards of imposing residential buildings could be increased by the transpiration and shadowing of the vegetation planted there (LEHRMAN, J. 1980).

The right choice of building materials and structural forms improved the air comfort of the inner spaces, too, as they were fitted to the different heat absorption and emission properties and the diurnal temperature fluctuations of the individual house sections on the lower and upper storeys. The thick-walled, flat-fronted ground-floor rooms were massive block-like constructions, usually made of sandstone which slowly admitted the warmth of their environment and fairly delayed. Since they can also get rid of the thermal mass accumulated in them gradually prolonged in time, they are excellently suitable for stay in the daytime, but during the night they do not provide shelter for the residents of the houses. The exterior architectural forming of the upper storeys showed a completely different picture. On the whole, they were loosely structured, a few centimetres thick-walled building parts with carved and engraved decoration consisting of stone slabs reticulated by jalis and enriched by frontal elements protruding from the wallfaces which, contrary to the bottom floor, relatively quickly warm up, but during the cooling off in the evenings they are able to release the thermal mass accumulated in them in the daytime similarly fast. However, the late hours in the hottest months of the year are tolerable only in the open air; therefore, people gather on the roof level in the evenings and spend even their nights there. In areas which receive a significant amount of rainfall during the wet season, attachment structures, the so-called saywans consisting of discontinuous lath wall and thin metal roof sheet were erected which do not obstruct the withdrawing of thermal masses during the superficial radiation intensifying in the late evening and at night, however, they provide protection against the rain (GUPTA, V. 1981).

The natural ventilation realised through routed motion of air is also served by badgirs, the widespread windcatcher towers that have determined the urban landscape since the early antiquity in the *Iranian Basin*. These towers built next to residential buildings and vaulted reservoirs are usually four, but occasionally six or eight-sided constructions that are connected by their foundations to the buildings desired to ventilate and on their top depending on the direction of wind and the mode of operation on one or more sides openings can be found which make the capture and departure of air possible. Badgirs open only on one or on two opposite sides were used where wind typically blows in the same direction; while in regions, where the direction of wind is changeable, windcatcher openings were normally formed on both sides. Inside the badgirs open on more sides, wind channels are located appropriate to the numbers of the windcatcher openings which are separated from each other by a dividing unit named shaft stretching down from the top of the tower till the residential levels.

The windcatcher towers utilising the kinetic energy of wind and the vertical motion of air as a result of change in temperature are suitable for three kinds of working methods (A'ZAMI, A. 2005). The most common is the primary function of badgirs based on the capture of wind. In this case, the tower extending upwards catches a high energy air beam through its opening which faces the direction of wind and this retaining its weight starts to move downwards in the given flue and then reaching the residential levels enters the airspace of the building. From the living spaces, the air gets out through the opposite side counterpart of the windcatcher opening and its wind channel respectively. It is possible, because the wind passing around the tower in contrast with the compressive force exerted on the opposite side displays a suction effect at the opening located in the direction of the windflow, but with its back to that, so it can sniff the air out from the building through the connecting flue. The air current captured into the badgir and exhausted through it provides a mild draught in the premises of the house.

The windcatcher towers, where it is possible, are connected with the essential accessories of irrigation doing along pediments of arid and semi-arid areas, called *qanats* in *Iran*. These are nothing else than slightly sloping artificial tunnels, one end of which is drilled into the groundwater collecting layers of mountain ranges, and the other one joins the irrigated lands through a surface channel. Utilising qanats, the evaporation of water flowing in them can be prevented. The qanats are hollowed out through shafts which are located in roughly equal distances and sunk in vertical direction. The badgirs linked with these water delivery tunnels possess only one opening situated on the leeward side. The warm airflow entering the air transport system through the vertical shafts of the qanats and passing the cold water tunnels turns chilly noticeably, then gets into the buildings built over the qanats via the pipes leading to their basement premises. It leaves the living spaces through the aperture of the badgir as described above, by the means of the suction force of wind blowing along the top of the tower. It is also helped by the upward streaming airflow which gets warm in the building. The most efficient air conditioning can be achieved by the use of qanat connected windcatcher towers, since the air stream arriving through the irrigation tunnels and departing across the badgirs not only ventilates but also cools the inner spaces.

The badgirs can also be utilised in case of windless weather, then the convective reversal of air resulting by its changes in temperature is used to maintain the air motion. In the daytime, cooler air enters the buildings through their northern, shaded frontal apertures and also moves down across the flues of the windcatcher towers shadowed, as well. It is then pulled out by the air current warming and rising up in the southern wind channels of the badgirs exposed to the direct radiation of the *Sun*. A different current system operates at night as the external air cooling down and getting heavier as a result of the thermal absorption of the strong terrestrial radiation that moves downwards in each flue of the windcatcher towers. At the same time, thermal masses of the premises get warmer by the end of the day coming out through the apertures of the houses; they ascend and so take over the airflow arriving across the wind channels of the badgirs.

4. A possible solution: contemporary use of conventional ventilation methods

Some technical designers in present days are already inspired by the natural architectural methods of climatisation not requiring additional energy resources outlined above. Fortunately, in the last years and decades a number of constructions, making use of passive ventilation and heat tempering procedures, have sprung up worldwide, out of which we would like to draw attention to two Indian public buildings in conclusion.

The building of *Torrent Research Centre*, a pharmaceutical institution located in the *Ahmedabad–Gandhinagar agglomeration*, the economic, cultural, administrative and scientific centre of *Gujarat*, which was built on the basis of *Nimish Patel* and *Parul Zaveri*'s plan and had been completed by 1999 can be considered as one of the most eminent contemporary examples of air comfort improvement that is implemented by the use of windcatcher towers. In this construction, a method has been introduced which combining the ventilation of trapped air and the heat extraction effect of water increases the efficiency of air conditioning. The essence of the procedure called *passive downdraught evaporative cooling (PDEC)* is that the air current got into the aeration system through the wind channels of the towers is led across a microscopically vaporised fine rain. The research site of the Torrent Group in *Ahmedabad* consists of six blocks out of which four uses PDEC-technology based climatisation only. Due to this method, on the one hand, the indoor air temperature compared to the outdoor one is 12–13°C (53.6–55.4°F) lower and the diurnal temperature fluctuation is not more than 3–4°C (37.4–39.2°F). On the other hand, by means of PDEC, the efficiency of the ventilation is so high that the building can provide continuous occupation for even 600 persons in contradiction to the 150–175 planned in advance. Besides, the cost-benefit calculations based on the experiences of the operation now show that the additional capital requirements of the PDEC system as a consequence of the significant fall of the power consumption recovered within one year. Moreover, even the investment costs of the whole construction project can be returned in 15 years (THOMAS, L. – BAIRD, G. 2006; PALACIOS, D. 2007).

One of the newest modern-day adaptations of the formal solutions of the traditional Indo-Islamic architecture serving passive aeration and air cooling is the educational centre of the 5, the institute playing a leading role in fashion and design training in *India* which has been dreamed in *Manit* and *Sonali Rastogi*'s architect studio and was opened in 2008 in *Jaipur*. The creators have based their architectural conception on the ancient methods of air comfort improvements presented above. Out of them, they gave all their attention to apply jalis to shade and baoris to cool air (ARCHDAILY ONLINE, 2009). The most prevailing detail of the conspicuously closed, introverted compact building situated in an industrial park, approximately 20 km (12.4 mi) far from the centre of the seat of the hot and arid *Rajasthan* is the perforated pattern metal frame placed around about 1.2 m (3.94 ft) in front of the façade which looks as a modern but less expressive reminiscence of the ancient stone-carved jalis. This structural element provides not only for filtering light rays, but it also serves to enclose a thermal buffer zone around the exterior wall front which delays the heat effect of the solar radiation *(Figure 5)*. The water reservoir being equivalent to a baori has been formed through a several metres step-sided lowering of the ground level *(Figure 6)*.

This recessed area would be able to create a pleasant microclimatic environment even by itself as a result of its temperature which compared to that of the surface of earth is lower. Its effect can be further enhanced by evaporation, in the case of proper use of the water basins, shading of the wings protruding into the courtyard and the ventilation of air currents creeping in diagonally from the open pavement level of the house.

The author's generally positive impressions obtained during his visit of the building in October 2012 have been overshadowed a little only by the fact that he discovered a series of equipment looking like AC devices in the thermal buffer zone behind the metal jali screen *(Figure 7)* and he did not find even a drop of water in the basins destined to fulfil the functions of a baori.

Figure 5 – Metal jali skin on the Pearl Academy of Fashion, Rajasthan
Photographed by ZAGYI, N. (2012)

Figure 6 – Courtyard of the building of Pearl Academy of Fashion imitating a stepwell
Photographed by ZAGYI, N. (2012)

Figure 7 – Thermal buffer zone with AC looking devices, Pearl Academy of Fashion

Photographed by ZAGYI, N. (2012)

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