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SUSTAINABLE AIR-CONDITIONING FOR OFFICE BUILDINGS IN THE TROPICS

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Summary

Tropical climates are thermally uncomfortable and are mostly unhealthy to the occupants of the modern skyscrapers, both residential and commercial buildings. The outdoor air dry bulb temperatures are on the hot side coupled with high relative humidity's. The population living in the tropics, especially in countries like Malaysia, is affluent and can afford to air-condition their residences and offices. Installation of air-conditioners is almost synonymous with prestige. This way of living leads to increased electricity usage and energy consumption in the buildings. However, switching-off the air-conditioning is not an option for the modern day buildings, as it would affect the health of the people as well as their productivity. This paper proposes innovative indoor units that will contribute to energy conservation by utilising principles of partial air-conditioning. The outdoor units could be utilised for clothes drying or for providing hot water to the occupants of the building of residential buildings, thus reducing the energy requirements in the buildings. Thus the utilisation of partial air-conditioning will lead to enormous savings in energy consumption in the buildings.

1.0 Introduction

In the humid tropical climate of Malaysia, the differences between indoor and outdoor air temperatures are not high. Sun is the single most important natural element to be considered in the building design. It affects almost every design decision and has a direct impact on the energy budget of the building. Thermal Comfort analysis may be used to assess a given environment and is important in determining an energy management strategy in buildings. The human body temperature regulation determines the physiological thermal comfort of the occupant of a room, as the human body exchanges heat with the environment. Heat is exchanged by radiation, convection and evaporation. The heat is primarily produced by metabolism. During normal rest and exercise, this results in an average temperature of the vital organs of near 37 deg C. The body's temperature control system tries to maintain this temperature in the varying thermal environment.

2.0 Climate of Malaysia

The main features of a hot-humid climate like that of Singapore and Malaysia are the relatively uniform temperatures, small variations in the diurnal temperature variations (approximately 7 deg C). However the associated high relative humidity is high. Also, there is abundant rainfall due to the maritime exposure and proximity to the equator. Throughout the year the temperatures are fairly uniform. The mean monthly temperature does not vary by more than 1.1 deg C from the mean annual value of 26.6 C. The average diurnal variation of temperature is about 7.0 deg C. Excessively high or low temperatures are rarely experienced. For the period 1934 to 2007 the highest temperature recorded is 35.8 C and lowest is 19.6 C. The mean annual R.H. over the period 1934 to 2007 is 84%. However, there are large diurnal variations from 60% to 95%. The mean daily maximum and minimum values are 96% and 64% respectively. There are no distinct seasons and rainfall occurs during every month of the year. December is usually the wettest month of the year with an average monthly rainfall of 280 mm and July if the lowest with an average monthly rainfall of 160 mm.

Thus, the salient features of a hot-humid equatorial climate are,

- high rainfall and high humidity, associated with a low diurnal range
- a relatively high and even temperature throughout the year
- light winds and long periods of still air
- high radiation intensities.
- rain usually in afternoon often accompanied by violent thunder-storms (Sumatra's)

2.1 Solar radiation intensities (Lim et al, 1979, Rao 1994)

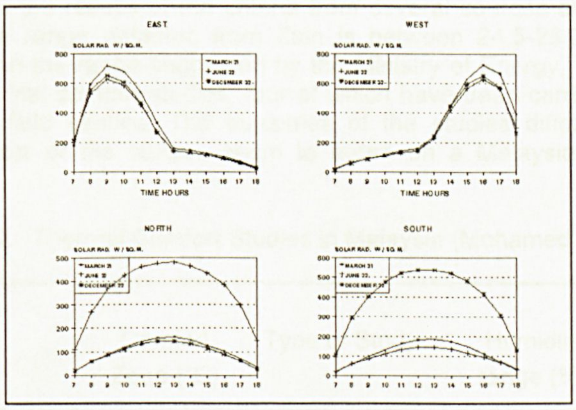


Figure 1 Typical Solar Radiation Intensities in Singapore measured data (Rao 1994)

Figure 1 shows the measured solar radiation intensities for Singapore. Table 1 (Mohamed Ali. 2004 and Malaysian Meteorological Office) is a summary of 30-year average of dry bulb temperatures, relative humidity's and mean wind velocities for various months in Kuala Lumpur, Malaysia. It experiences high relative humidity, varying from 67% to 96 % with an average value of around 80%. The outdoor air temperature varies from 24 deg C to a maximum of 33 deg C. There is no dominant wind direction.

TABLE 1 Monthly Means of Outdoor Air Temperatures, Relative Humidities and Wind Speeds Kuala Lumpur, Malaysia. (Mohamed Ali. 2004 and Malaysian Meteorological Office)

	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Temp.deg C	26.9	27.2	27.5	27.6	27.7	27.8	27.3	27.3	27.1	27.0	26.6	26.6	27.23
Mean Max. Temp deg C	32.5	33.3	33.5	33.5	33.3	33.1	32.6	32.7	32.5	32.5	32.1	31.9	32.79
Mean Min. Temp deg C	23.1	23.4	23.8	24.2	24.3	24.1	23.7	23.7	23.6	23.7	23.6	23.3	23.71
R.H %	78.4	78.2	79.3	81.5	80.6	78.9	78.9	78.9	80.6	81.6	83.6	81.9	80.20
Mean Wind Speed (m/s)	1.02	1.10	1.06	1.00	1.00	1.07	1.17	1.15	1.03	1.16	0.97	0.90	1.05

2.2 Thermal comfort in the Hot-humid climate (Ellis 1953, Humphreys 1975, Lim et al 1979,Mohamed Ali 2004, Rao et al 1979,Rao 1993, Webb 1959)

Creating a thermally comfortable environment is one of the parameters to be considered when designing buildings. Thermal comfort has been defined as the condition of mind that expresses satisfaction with the thermal environment. The reference to mind emphasises that comfort is a psychological phenomena too. There is a wide variation in thermal requirements and in thermal sensitivity between individuals in a given group. The aim should be to create conditions for optimal thermal comfort to satisfy the highest possible percent of the group. Probably at best only 80% of the occupants would be comfortable at any one time under the best possible conditions. The individual differences in preferred temperatures would arise in part from the differences in the clothing, activity and acclimatisation to the local climate. Hence results of comfort studies made elsewhere may not necessarily be applicable to the Malaysian conditions.The factors, which affect indoor thermal comfort, are the air dry bulb temperature, humidity, air movement and solar radiation. In order to combine the effect of these factors several thermal comfort indices have been proposed. These indices attempt to combine the effect of two or more variables into a single variable on humans. Several such indices have been developed for the tropical climates.

2.2.1 Thermal comfort studies in Malaysia (Abdul Malik et al 1993, Zain Ahmed 2000, Mohamed Ali 2004)

For comparison purposes, the results of the criteria from several sources are summarized in Table 2. For example, the temperature range obtained from Zain is between 24.5-28.0 deg C, which is lower than Abdulmalik, but higher than the range suggested by the Ministry of Energy, Telecoms and Posts [13]. This table comprises eight thermal comfort studies, four of which have been carried out on Malaysians either in climate chambers or as field studies. The outcomes of the studies differ slightly due to different test procedures. However, most of the studies seem to agree on a Malaysian comfort zone of around air temperature of 25 deg C.

Table 2 Thermal Comfort Studies in Malaysia (Mohamed Ali. 2004)

Study	Comfort Zone (°C)	Type of Study	Humidity range (%)	Air Velocity (m/s)
Zain Ahmed	24.5-28.0	Field Study	72-74	0.3
Abdulmalik	25.5-29.5	Climate Chamber	45-90	-
Davis	24-28	Field Study	-	-
Ministry of Energy, Telecom and Posts, Malaysia	22.0-26.0	Field Study	-	-
Abdul Rahman	27.4	Climate Chamber	54 -76	0.1

3.0 Air-conditioning

Air-conditioning is defined as a process that heats, cools, cleans and circulates air and controls its moisture content. Ideally, it does all these simultaneously and on a year round basis. Thus air conditioning makes it possible to change the condition of the air in an enclosed area. Figure 2 shows a simple air-conditioning system

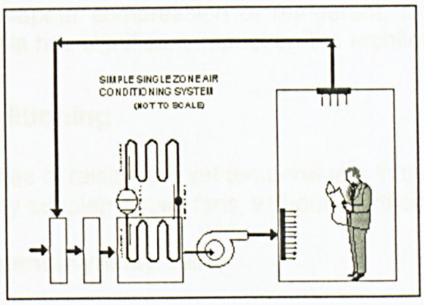


Figure 2 Simple Single zone air-conditioning system

3.1 Chilled water air-conditioning systems for typical tall building structures

Figure 3 shows a schematic layout of a chilled water system. In this system heat from air passing through the air-handling unit is collected by chilled water and is transferred to the refrigerant passing through the evaporator coil. The heat from the refrigerant is transferred to the cooling water in the condenser. The cooling water carries the heat away to the cooling tower where it is dissipated in the atmosphere. Thus the chilled water system is an indirect system where the refrigerant chills water, which is then circulated through pipe work to the air-handlin(

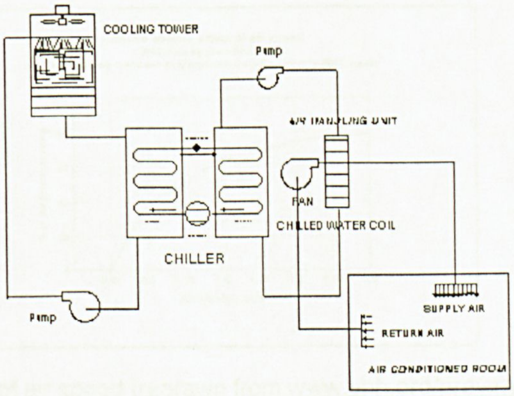
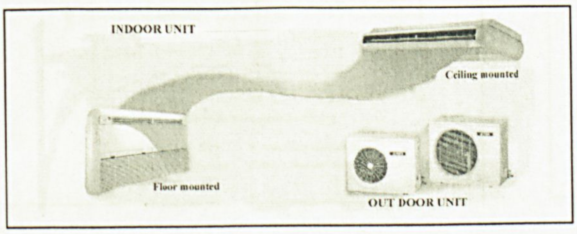


Figure 3 Chilled water air-conditioning system

3.2 Air-conditioning for residences in the hot-humid tropical climate



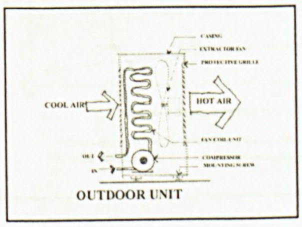


Figure 4 A typical split-system air-conditioning system for both high-rise and low rise residential units

Almost all of the split system air-conditioning units utilise the mechanical vapour compression refrigeration cycle shown in Figure 2. The split unit system contains two major elements: one is the indoor unit that blows the cool air, called fan-coil unit, second is the outdoor unit as shown in Figure 2, called a condenser unit. These two are linked with copper piping that carries the refrigerant gas. The out door unit work as chillers, where the refrigerant is compressed and pumped back to the indoor unit. The outdoor unit contains an electric motor to blow away the heat as a result of the mechanical vapour compression of refrigerant. It is worthwhile to study the various potential of this reusable energy, as it is has significant impact on the architectural design and environment such as in Malaysia

4.0 Concept of Partial air-conditioning

This section investigates the possibilities of raising the set temperatures in the air-conditioned space with appropriate increase in air-velocities by supplementary fans, without sacrificing occupant thermal comfort.

4.1 Cooling effect of air movement (Aynsley 2006)

The manual of Naval preventive medicine covers the cooling effect of air movement on people. Figure 5 is redrawn from the original, amplifying the region of air velocities of 0 to 2 m/s. There are several other sources indicating the cooling effects of air movement.

Figure 6 shows the effects on the Predicted mean votes (PMV) due to air movement at various dry bulb temperatures for air velocities of 0.1 m/s and 0.3 m/s. It can be observed that the DBT can be raised to 25 deg c in an air-conditioned office, provided the air velocity is held at 0.3 m/s. This will reduce the energy for cooling the supply air. This is the concept of partial air-conditioning.

Large ceiling fans can mix the air in atria to a uniform temperature. Aynsley (2006) demonstrates a system of de-stratification fans in an air conditioned atrium as shown in Figure 7.

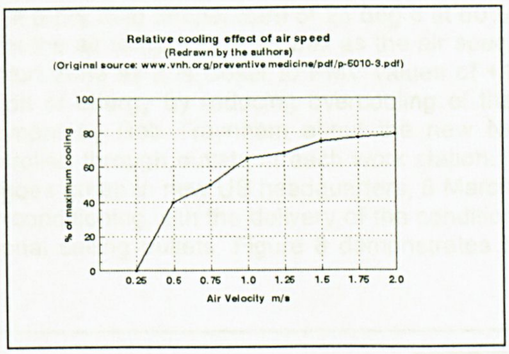


Figure 5 Relative cooling effect of air speed (redrawn from www.vnh.org/preventivemedicine, p3-7)

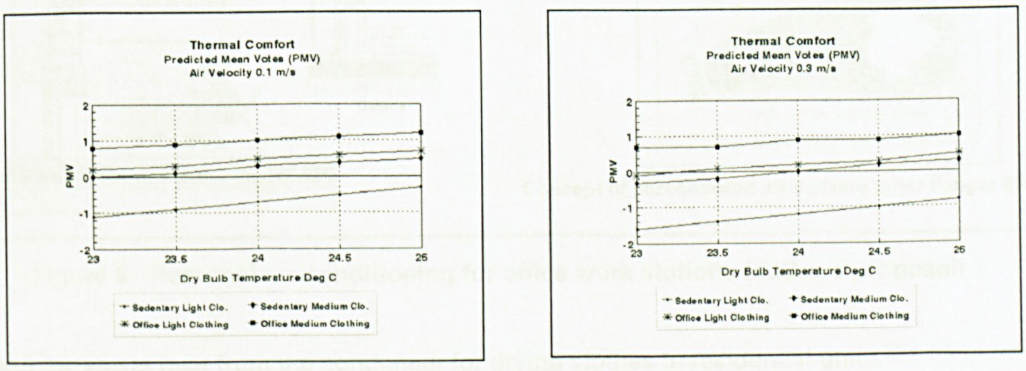


Figure 6 Predicted Mean Values for air velocities of 0.1 m/s and 0.3 m/s (based on Fanger 1972)

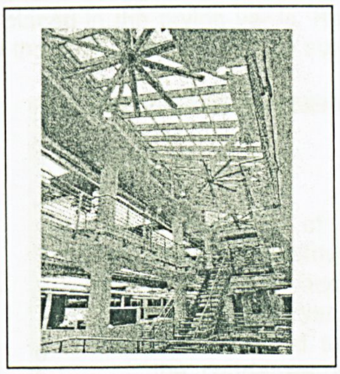
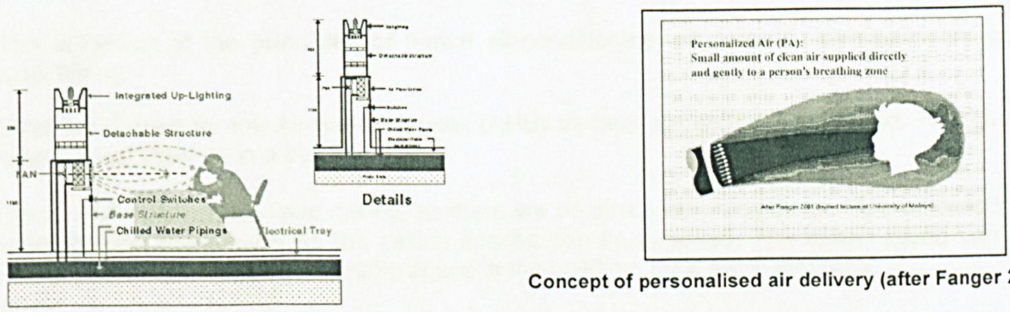


Figure 7 De-stratification fans in an air conditioned atrium (Aynsley, 2006)

4.2 Modified personal air-conditioning fan-coil units (Personal air-conditioning Systems) for effective partial air-conditioning

The concept of partial air-conditioning is proposed by the authors to provide adjustable personal environments to individual work stations in open plan offices. This involves the provision of individual air-conditioning outlets and delivery systems. Personal air-conditioning allows every office worker to gain control over their immediate thermal environment (Fanger 2001, Pan et al 2005). The air is delivered at a slightly higher velocity of 0.3 m/s and at a dry bulb temperature of 25 deg c at 60%R.H. The office worker could be provided with controls to control the air temperature as well as the air speed. As shown in Figure 6, this will still be within the thermal comfort zone as it is closer to PMV values of +1.00, which is comfortably warm. This would lead to conservation of energy by reducing overcooling of the space. This concept has been reinforced by the latest statement by Rob Traynham about the new Nissan headquarters in USA "Air conditioning and heat are controlled through outlets at each work station: You heat the people and not the space" (Yahoo News: Nissan goes green in new US headquarters, 8 March 2008). This firmly reinforces the authors' proposal of partial air-conditioning with the delivery of the conditioned air directly at the workstation and not through the conventional ceiling outlets. Figure 8 demonstrates the modified fan-coil units for air delivery at the work stations.

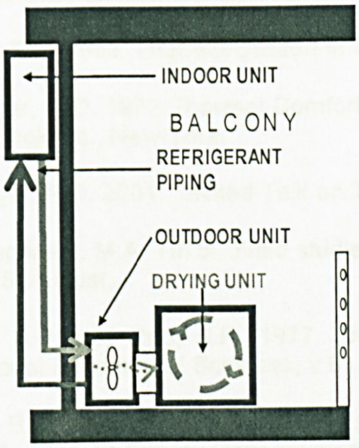


Concept of personalised air delivery (after Fanger 2001)

Figure 8 Personal air-conditioning for office work stations (authors proposal)

5.0 Using the waste heat from the condenser for drying clothes in residential units.

Currently the out door units are installed at the discretion of installer. The maximum length of the refrigerant copper pipes governs the limit of furthest distance. Usually there are no problems in selecting the location for the outdoor unit for the detached houses. It is easy to gather outdoor units together to collect the hot air from it. In comparison to the apartment unit, the designer usually would allocate a drying yard near the kitchen for laundry or general cleaning facilities. Out door unit could be placed in the drying yard and if the waste heat is channelled properly to help speed up drying the laundry. Tests have shown that temperature of the waste heat is about 40 ° C with the corresponding humidity of about 38 %. (Zunaibi et al 2002 and Rao et al 2005). Placing the outdoor units in the yard will help in reducing the number out door unit arbitrarily installed on the building facades. The average size of out door unit for 3 TR air-conditioning split unit systems is 1030x850x 400mm. Individual units of drying facilities can be placed in the drying yards. Re-channelling by capturing the hot air could reduce to muffle the noise created by the units. One unit of 1 hp outdoor unit could produce a noise level of about 60dB



CONCEPT:

- It consists of a standard commercially available electrical tumble-dryer unit.
- The heater module is disassembled from the tumble-dryer.
- This modified tumble-dryer is coupled with the condenser unit of the split system, by using suitably designed ducting.
- The whole assembly is designed to be arranged in the balcony to provide an aesthetically pleasing environment.

Figure 9 Use of condenser units for drying clothes in an apartment unit.(Zunaibi et al 2002, Rao et al 2005)

6.0 Conclusions

This paper proposes an innovative concept for the indoor units that will contribute to energy conservation by utilising principles of partial air-conditioning coupled with the personal air-conditioning systems. It has been proven that the air dry bulb temperatures can be raised upto 25 deg c with an accompanying air velocity of 0.3 m/s This does not compromise thermal comfort of the occupants of the office spaces. Because of the increase in the set-point temperature there will be a corresponding reduction in the air-conditioning cooling loads, leading to energy conservation. Also, the outdoor units could be utilised for clothes drying to the occupants of the residential buildings.

This will lead to enormous savings in energy consumption in the buildings and can be summarised as follows,

i. The utilisation of the principles of partial air-conditioning will lead to savings in energy for air-conditioning.

ii. There is no need for the Air-handling units (AHU) as they are no longer required. This saves valuable FLOORSPACE in a building.

iii. There is no need for the false ceiling, as there are no air-conditioning ducts. This will lead to a better interior architecture as the ceiling spaces can be exposed. The space saved can be utilised to provide additional rentable space in the building, for a given plot ratio.

iv. The personalised air-conditioning system is the most energy efficient system. The system will guarantee the best possible indoor air quality to the occupant of the space. (Most healthy environment).

v. Gives freedom to the architects and interior designers of office buildings to organise the workstations more efficiently. This in turn, will lead to better aesthetics.

vi. The waste heat from the Split-system air-conditioning units in residential units are used to dry clothes. This will eliminate electricity consumed for drying clothes in a tumble dryer. Also, it will lead to a more aesthetically pleasing building exterior. This will lead to a better quality of life for the residents

7.0 References

Abdul M.A and Young,A., 1993. Thermal comfort study as an aid to determine energy savings in buildings in Malaysia. Proceedings ENERGEX 93,Vol II, Seoul.

Aynsley, R. 2006. How air movement saves energy in indoor environments. AIRAH Sustainabilty Conference for tropical and sub-tropical climates, Noosa, Australia.

Ellis, E.P. 1953. Thermal comfort in warm and humid atmospheres. Journal of Hygiene, v 51.

Fanger, P.O. 1972 Thermal Comfort: analysis and applications in environmental Engineering. McGraw-Hill Book Co., New York.

Fanger, P.O. 2001. Invited Talk on Thermal Comfort, University of Malaya, Malaysia

Humphreys, M.A. 1975. Field studies of thermal comfort compared and applied. BRE Current paper CP 76/75, August.

Lim, B.P. and Rao, K.R. 1977. Thermal comfort studies in some Singapore schools, J. Singapore National Academy of Sciences, v 6.

Lim, B. P, Rao, K.R and Rao, S P, 1979, Air conditioning in Singapore - Is it necessary? In Proceedings, Conference on Energy Conservation & Management in Buildings, Singapore, pp. 108-138.

Lim, B.P and Rao, K.R. 1984. An integrated approach to environmental comfort with low energy. Energy conservation in the design of multi-storey buildings, Ed. H.J. COWAN, Pergamon press,

Malaysian Meteorological Office, Petaling Jaya, Selangor, Malaysia (1970-2007) Annual weather data

Mohamed Ali. 2004. Dynamic Thermal Performance Of The Living Room In The Terraced House In The Klang Valley, Malaysia. Ph.D thesis, University of Malaya. (Unpublished)

Naval Medical Command, Washington D.C. Manual of naval preventive medicine chapter 3 ventilation and thermal stress ashore and afloat, www.vnh.org/preventivemedicine, p3-7.

Pan, C.S, Chiang, H.C, Yen, M.C and Wang, C.C. 2005. Thermal comfort and energy saving of a personalized PFCU air-conditioning system. Energy and Buildings v 37, pp 443–449

Rao, K.R and Ho, J.C.1979. Thermal comfort in hawker stalls in Singapore, Applied research corporation, Singapore

Rao, S.P. 1991. Thermal comfort and the Design of personal environments in INDOOR ENVIRONMENT, National University of Singapore, ISBN 9971-62-375-0,

Rao, S P, 1993. Environmental factors for consideration in urban development. Singapore Institute of Architects Journal, 176, Jan/Feb, pp 9-14, Singapore

Rao, S P, 1994. Dynamic Thermal Performance of Buildings in the Singapore Climate. School of Architecture, National University of Singapore, Singapore. 495 pp. (Final Report).

Rao S P and Zunaibi Abdullah. 2005. CoolFan an innovative personal air-conditioning system for a sustainable future in the tropics, IPPP exhibition on Research and Innovation, University of Malaya, Kuala Lumpur, Malaysia, June 2005.

Webb, C. G. 1959. An analysis of some observations on thermal comfort in an equatorial climate", British J of Ind. Medicine, v16, pp 297-310.

Yahoo News : Nissan goes green in new US headquarters 8 March 2008
http://news.yahoo.com/s/ap/20080308/ accessed on 10 March 2008 at 10:30 am.

Zain Ahmed, A. 2000 Daylighting and Shading for thermal comfort in Malaysian buildings, Ph.D thesis, Universiti Technologi MARA and Universiti Kebangsaan Malaysia, Malaysia (Unpublished)

Zunaibi Abdullah and Rao, S P. 2002. "Use of waste heat from residential air-conditioners in a hot humid climate" World renewable energy congress, Cologne, Germany , Ed: AAM Sayigh, June, Elsevier, USA

Zunaibi Abdullah and Rao, S P. 2004. CoolFan – Energy conserving personal cooling system, World Renewable Energy Congress VII, Linking the world with Renewable Energy, Aug, Colorado, USA, Ed: AAM Sayigh, ISBN 008 044470 9, Elsevier, USA.