MW JOURNAL

Solar net fan: a potential tool to enhance bednet usage in hot climates

Olivier J.T. Briët[1,2]*

[1]Swiss Tropical and Public Health Institute, Basel, Switzerland

[2] University of Basel, Basel, Switzerland

*olivier.briet@unibas.ch

Abstract

Background. In recent years, many millions of bednets have been distributed to combat malaria. However, a substantial proportion of the recipients do not use their nets at all or year-round. The major stated reason for this is that they are hot and stuffy to sleep under during hot weather. A fan could bring relief by replacing the air inside the net, and also by providing wind to increase convective heat loss and heat loss by evaporation. However, a fan appears to be out of reach for those without access to electricity. **Presentation of the hypothesis.** The question arises whether or not a low cost, low energy solar fan system comprising of a pedestal mounted fan suitable for use inside bednets, a deep cycle battery and a small solar panel, might increase net usage and be affordable to off-grid populations at risk of malaria. **Testing the hypothesis.** This could be tested in a rural tropical setting by distributing solar net fan systems to random households owning nets. Net use behaviour of participants would be monitored regularly, and at the end of the study, the economic value would be assessed by willingness to accept and willingness to pay surveys. **Implications of the hypothesis.** If low energy solar net fan systems are affordable, they could improve the quality of life of people living in off-grid tropical conditions, by providing cooling and also by powering small lights, which could replace candles and kerosene lamps, which are a major cause of holes in nets. If the net fan systems also enhance bednet use, they could contribute to reducing transmission of malaria and other diseases transmitted by insects at night, also at times when the nuisance of mosquitoes is deemed insufficient to suffer the inconvenience of sleeping under a ventilation blocking net.

1. Background

Insecticide treated bednets (ITNs) are the most important and effective intervention for malaria prevention. Current recommendations for malaria-endemic settings are that all people should regularly sleep under an ITN [1]. Between 2008 and 2010, an estimated 290 million long lasting insecticidal nets have been distributed in sub-Saharan Africa (SSA) [2]. However, many bednet owners do not use it year-round. The major stated reason for not using a bednet, besides not owning a net, is that it is hot and stuffy to sleep under during hot weather [3-11]. The second most stated reason, low mosquito density [12], is not a barrier to use, and the reverse, high mosquito density, is a facilitator to use. Indeed, monthly data from Rowland and colleagues [13] show a strong linear relationship (quasi R-squared = 0.84) between the log transformed mosquito density and the logit transformed proportion of self reported net use. The decision whether or not to use a bednet is probably based on a trade off between discomfort caused by heat, stuffiness, and other barriers to use, such as the inconvenience of hanging it in a small space on one hand, and perceived risk of (infectious) mosquito bites and other facilitators to use on the other hand. Thus, for those interview respondents that mentioned low mosquito density as a reason for non use, the disincentive might actually be heat and stuffiness. In surveys in Burkina Faso, Ghana, Gambia and Kenya, net usage was between 1.2 and 5.0 times higher in rainy, cooler months than in dry and hotter months [6,14]. In India, studies show that nets are the preferred method of preventing mosquito bites, except during the hot humid season when they are perceived as being too hot to sleep under [16-18]. Similar findings are reported from the Solomon Islands [19]. In contrast, in a study in Oromia and Amhara Regional States, Ethiopia, very few people stated feeling too hot or ”suffocated” as reasons for not using ITNs [20]. These Ethiopian regions are at high altitude, where temperatures are considerably cooler.

The findings that temporal patterns in net use appear to be correlated with mosquito nuisance and possibly hot weather can be problematic for the effectiveness of ITNs, particularly because malaria transmission risk is not necessarily temporarily correlated with the overall nuisance caused by vector and non-vector species. Education and behaviour change communication (BCC) might increase bednet usage during periods of low mosquito nuisance. However, ”modifications to mosquito nets or the mosquito net using environment that render the mosquito net more comfortable would usefully complement any educational or BCC campaign" [12].

For over a century, people have known that the nets block ventilation thereby making them 'stuffy' [21]. The thermal (dis)comfort experienced at night depends on the relative humidity, temperature, air velocity, metabolic activity and clothing insulation, as well as on personal factors such as acclimatization. Mosquito net manufacturers try to facilitate ventilation by making the mesh size as large as possible [19], but are limited to a maximum size that still restricts (nuisance) insects from entering. A net may not only reduce air velocity (important for both convective heat loss and heat loss by evaporation), it may also partially trap the metabolic heat and evaporated water produced by the occupant(s). Inside most houses, at night, the air velocity is probably very low, and the main (indirect) effect of the net on thermal comfort (See Appendix) is probably to increase the temperature and humidity inside the net environment. In hot and humid environments, sleeping under a net can thus be uncomfortable.

A fan can bring relief by assisting the replacement of the hotter and more humid air inside the net by the cooler and drier air outside the net environment, and also by providing wind to increase convective heat loss and heat loss by evaporation. However, this simple solution appears to be out of reach for the 585 million people (69.5% of the population) living in SSA without access to electricity [23]. In rural SSA, where malaria transmission is generally higher than in urban areas, 85.7% of the population does not have access to electricity. Some of the more malarious countries in South East Asia also have a high proportion of people living without access to electricity (e.g. Myanmar 87%; Cambodia 76%) [23]. For people not connected to the main electricity grid, solar cells may provide an alternative electricity source. The cost of solar cells has been prohibitive in the past, but the price has decreased exponentially since the 1980s and is currently under 2 US$ per watt [24]. However, the factory cost of a complete small solar electricity kit (including battery) is 10 US$ or more, depending on capacity (see Appendix). The question arises whether or not a low cost, low energy fan powered by solar cells might increase ITN usage and be affordable to off-grid populations at risk of malaria.

2. Presentation of Hypothesis

The hypotheses presented here are that i) a low energy solar net fan system is desirable and economically affordable for a large part of the population in rural settings in SSA, and ii) access to a low energy solar net fan system will increase bednet usage in areas with a hot climate.

In order to be within economic reach of and desired by a substantial part of the rural population, a solar net fan system would need to be as cheap as possible while providing sufficient cooling. The most expensive components of the system would be the solar panel and the storage battery, necessary to operate the fan at night. Low energy box fans, mostly used for cooling computer hardware, are relatively cheap and are available in a range of capacities. The lower the energy requirement of the fan, the lower the cost of both solar cells and battery. The trade off is that the ventilation capacity of the fan will decrease with the decreasing energy requirement, yet the ventilation capacity should be high enough to noticeably increase the comfort of bednet occupants.

Both the capacity of the fan and the way the fan is mounted are crucial for a successful design. In order to make maximum use of the cooling airflow from a fan, the fan should be positioned inside the net and directed toward the occupant(s). The mounting of the fan should not risk damaging the net or impede its normal function. In conical nets, a fan could easily be suspended from the frame, requiring only string and four safety pins. The high central position may require the power cables to transverse the net, which could enhance the possibility of the net tearing. Such a mounting has the advantages of being cheap and of distributing airflow centrally over the bed. However, the fan would blow air downward. Because hot air rises, the air higher in the net (and the room) is generally warmer than the air nearer to the floor. In a downward blowing design, the warmer air is blown towards the occupant, in the opposite direction of the convection currents, which presumably are upwards near the centre (and possibly also toward the sides) of an occupied net. Also, such a design would not work for a frameless rectangular net, which is the most commonly (donor) distributed net type, or other net types such as A-frame nets and triangular nets. In a frameless rectangular net, the weight of the fan would pull the corners of the net towards the centre, deforming the shape of the net.

Therefore, a slightly more complicated design is proposed here, with the fan standing on a pedestal (Fig. 1), which is suitable for all net types, except hammock nets. The pedestal should be designed in such a way that it can be wedged between a mattress and bed, and does not preclude tucking the net in, and can be free standing in case a mattress is not available. Such a design does not deform the shape of the net; if anything, in conical nets, it helps hold the net away from the occupant's body. Also, the cables do not need to cross the net barrier. A possible disadvantage of this setup is that the airflow might be less evenly distributed over the bed than with the fan in a high central position. Also, a standing fan could be an obstacle in often-cramped rooms during the day. Furthermore, a fan mounted on the net would automatically promote net use, whereas a free-standing fan could also be used without hanging and spread-

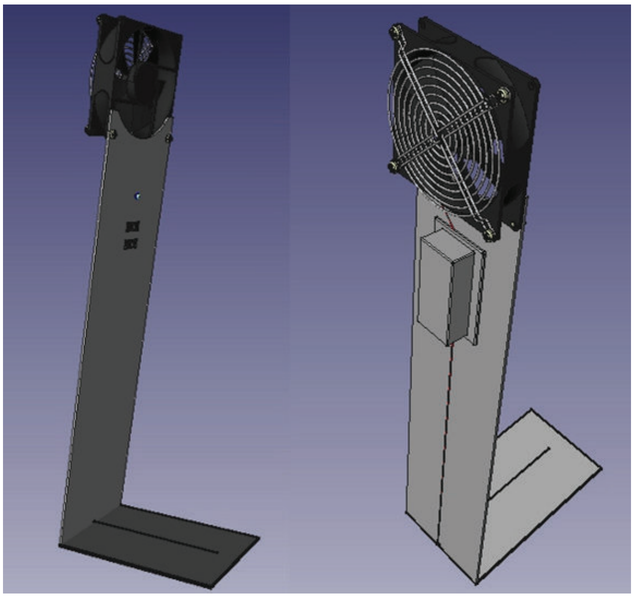

Figure 1. *A computer box fan (in this design with dimensions 12 × 12 × 2.5 cm) is mounted on a pedestal, which makes a ten degree angle with the floor surface, for stability and for blowing air slightly downward. In this design, the pedestal has a LED light with separate switch.*

ing a net. Therefore, multiple designs should be tested.

3. Testing the hypotheses

The hypotheses could be tested in a rural tropical setting by distributing solar net fan systems to random households owning bednets. Possibly, this would be in an area where a large proportion of the people have received donor distributed bednets, and where use is suboptimal. Net use behaviour of participants would be monitored regularly over the course of a year, and at the end of the study, fan recipients would be asked for how much money they would be willing to sell their (donated) solar net fan system (i.e. a willingness to accept study). Both recipient and non-recipient participants would then be asked how much they would be willing to pay for a solar net fan system. This, together with manufacturing information, would give an indication whether solar fan systems might be economically feasible.

4. Implications of the hypotheses

If low energy solar net fan systems are affordable, they could improve the quality of life of people living in off-grid tropical conditions, not only by providing cooling, but possibly also by powering small light emitting diode (LED) lamps and as sources to charge mobile phones, features that could easily be added to the design. Use of electric lights could replace the use of candles and kerosene lamps near beds, which is a major cause of (burn) holes in nets [25]. If the net fan systems also enhance bednet use (and net durability), they could contribute to reducing transmission of malaria and other diseases transmitted by insects at night. In areas with year round transmission but seasonal net usage [4,14], net fans would increase usage at times when the nuisance of mosquitoes is deemed insufficient to suffer the inconvenience of sleeping under a ventilation blocking net.

5. Acknowledgements

The author acknowledges Christian Lengeler, Pie Muller, Danica Jancaryova, Nicolas Maire, Diggory Hardy and Tom Smith for help testing concepts. The author declares that he has no competing interests.

References

1. World Malaria Day 2010: Africa Update. In *Progress & impact series*. UNICEF; 2010, -44.
2. World Health Organization: World malaria report 2010, 2010.
3. Binka F, Kubaje A, Adjuik M, Williams LA *et al.*: Impact of permethrin impregnated bednets on child mortality in Kassena-Nankana district, Ghana: a randomized controlled trial. *Trop. Med. Int. Health* 1996, **1**: 147-154.
4. Baume CA, Marin MC: Intra-household mosquito net use in Ethiopia, Ghana, Mali, Nigeria, Senegal and Zambia: are nets being used? Who in the household uses them? *Am. J. Trop. Med. Hyg.* 2007, **77**: 963-971.
5. Winch PJ, Makemba AM, Makame VR, Mfaume MS *et al.*: Social and cultural factors affecting rates of regular retreatment of mosquito nets with insecticide in Bagamoyo District, Tanzania. *Trop. Med. Int. Health* 1997, **2**: 760-770.
6. Frey C, Traore C, De Allegri M, Kouyate B *et al.*: Compliance of young children with ITN protection in rural Burkina Faso. *Malar. J.* 2006, **5**:70.
7. Holtz TH, Marum LH, Mkandala C, Chizani N *et al.*: Insecticide-treated bednet use, anaemia, and malaria parasitaemia in Blantyre District, Malawi. *Trop. Med. Int. Health* 2002, **7**: 220-230.
8. Pettifor A, Taylor E, Nku D, Duvall S *et al.*: Bed net ownership, use and perceptions among women seeking antenatal care in Kinshasa, Democratic Republic of the Congo (DRC): opportunities for improved maternal and child health. *BMC Public Health* 2008, **8**: 331.

9. Alaii JA, van den Borne HW, Kachur SP, Shelley K *et al.*: Community reactions to the introduction of permethrin-treated bed nets for malaria control during a randomized controlled trial in western Kenya. *Am. J. Trop. Med. Hyg.* 2003, **68**: 128-136.

10. Njoroge FK, Kimani VN, Ongore D, Akwale WS: Use of insecticide treated bed nets among pregnant women in Kilifi District, Kenya. *East Afr. Med. J.* 2009, **86**: 314-322.

11. De La Cruz N, Crookston B, Dearden K, Gray B *et al.*: Who sleeps under bednets in Ghana? A doer/non-doer analysis of malaria prevention behaviours. *Malar. J.* 2006, **5**:61.

12. Pulford J, Hetzel MW, Bryant M, Siba PM *et al.*: Reported reasons for not using a mosquito net when one is available: a review of the published literature. *Malar. J.* 2011, **10**:83.

13. Rowland M, Webster J, Saleh P, Chandramohan D *et al.*: Prevention of malaria in Afghanistan through social marketing of insecticide-treated nets: evaluation of coverage and effectiveness by cross-sectional surveys and passive surveillance. *Trop. Med. Int. Health* 2002, **7**: 813-822.

14. Korenromp EL, Miller J, Cibulskis RE, Kabir CM *et al.*: Monitoring mosquito net coverage for malaria control in Africa: possession vs. use by children under 5 years. *Trop. Med. Int. Health* 2003, **8**: 693-703.

15. Krezanoski PJ, Comfort AB, Hamer DH: Effect of incentives on insecticide-treated bed net use in sub-Saharan Africa: a cluster randomized trial in Madagascar. *Malar. J.* 2010, **9**:186.

16. Tyagi P, Roy A, Malhotra MS: Knowledge, awareness and practices towards malaria in communities of rural, semi-rural and bordering areas of east Delhi (India). *J. Vector Borne Dis.* 2005, **42**: 30-35.

17. Gunasekaran K, Sahu SS, Vijayakumar KN, Jambulingam P: Acceptability, willing to purchase and use long lasting insecticide treated mosquito nets in Orissa State, India. *Acta Trop.* 2009, **112**: 149-155.

18. Jambulingam P, Gunasekaran K, Sahu S, Vijayakumar T: Insecticide treated mosquito nets for malaria control in India-experience from a tribal area on operational feasibility and uptake. *Mem. Inst. Oswaldo Cruz.* 2008, **103**: 165-171.

19. Atkinson JA, Bobogare A, Fitzgerald L, Boaz L *et al.*: A qualitative study on the acceptability and preference of three types of long-lasting insecticide-treated bed nets in Solomon Islands: implications for malaria elimination. *Malar. J.* 2009, **8**:119.

20. Baume CA, Reithinger R, Woldehanna S: Factors associated with use and non-use of mosquito nets owned in Oromia and Amhara regional states, Ethiopia. *Malar. J.* 2009, **8**:264.

21. Hill L, Fink GH: The air inside a mosquito net. *Br. Med. J.* 1910, **2**: 1190.

22. Haddow AJ: The mosquito fauna and climate of native huts at Kisumu, Kenya. *Bull. Entomol. Res.* 1942, **33**: 91-142.

23. WEO-2011 new Electricity access (2009 data country-by-country) [http://www.iea.org/weo/docs/weo2011/other/Energy_Poverty/WEO-2011_new_Electricity_access_Database.xls]

24. Retail pricing environment [http://www.solarbuzz.com/sites/default/files/facts_figs/SB_Retail_Pricing_111108.xlsx]

25. Kilian A, Allan R: Net durability update Uganda, Nigeria and Chad. 2012, Slide 8.

26. Fanger PO: Assessment of man's thermal comfort in practice. *Br. J. Ind. Med.* 1973, **30**: 313-324.

27. Olesen BW: Thermal comfort. In Technical Review. Bruel and Kjaer; 1982, **2**: 1-42.

28. IRI/LDEO Climate Data Library [http://iridl.ldeo.columbia.edu/]

Appendix

Thermal comfort

The predicted mean vote (PMV) about thermal comfort (Fig. i) might be used to obtain an idea of the degree of discomfort a naked resting adult might experience, depending on the environmental conditions (e.g. those inside a net) while assuming no airflow other than convection.

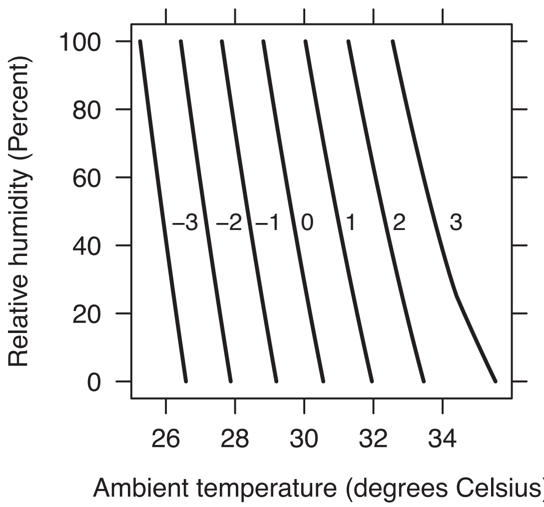

Fig. i. Predicted mean vote against temperature and relative humidity. *Plot of the predicted mean vote (PMV) of a large group of naked resting subjects about thermal comfort according to a psycho-physical scale (+3 = hot, +2 = warm, +1 = slightly warm, 0 = neutral, -1 = slightly cool, -2 = cool, -3 = cold) depending on relative humidity and ambient temperature, with only convection current, inside, at sea level [26,27].*

Alternatively, the humidex, an index to describe how hot the weather feels to the average person, combining the effect of temperature and humidity, may be useful to describe when and where bednets may be experienced as hot (Fig. ii). A humidex of over 30 is deemed to give some discomfort. The isolines for the humidex are a lot flatter than for the PMV (Fig. i), giving higher importance to the relative humidity. It should be noted that the humidex does not take variable air velocity (wind) into consideration, whereas this is possible for the PMV calculation.

Figure iii shows that in most of the tropics, except at higher altitudes, discomfort is expected in the evening around bedtime for at least one month per year. Although the humidex declines during the course of the night, the humidex of the air inside traditional houses is higher than that of the outside air between 7 PM and 9 AM (Fig. iv). In Kisumu, Kenya, the humidex is about 1.5 index points

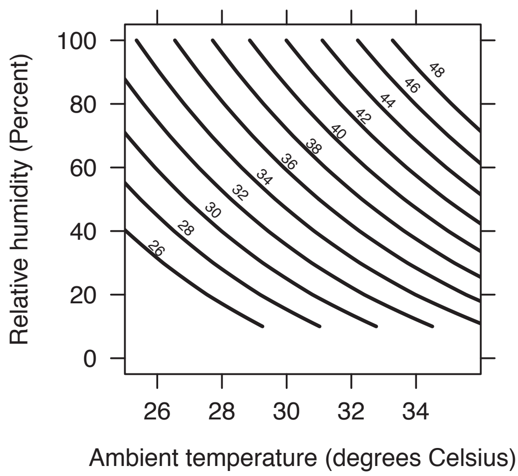

Fig. ii. Humidex against temperature and relative humidity*.*

higher at 9 PM than it is indoors [22]. Presumably, due to accumulation of hot humid air, the climate inside an occupied net is even higher.

Cost assessment of a low energy solar net fan system

At the design stage of the system, it is difficult to give more than a very rough indication of what a low energy solar net fan system could cost. The most costly component is undoubtedly the energy provision: a solar panel, storage battery and charge controller, and much depends on the required capacity and durability. Solar light kits including one or more 20+ LED (one watt or more) compound lamps (but no fan) are available on the market (Table A1).

If a minimum fan capacity of 1 watt is assumed, the lowest capacity systems may not be able to power a single fan for a full night, especially not if charging during the day is less than optimal during the rainy season. The larger capacity kits will have a longer life expectancy as the battery will be less deeply discharged per cycle, and can power more than one fan per household. For a fan system kit, the compound LED should be replaced by a weaker LED, and a fan and pedestal added. Box fans are relatively cheap compared to the solar light kits at about 0.7 - 1.5 US$ per unit. The cost of a pedestal is unknown and depends on the final design, but will probably be a small component of the total cost.

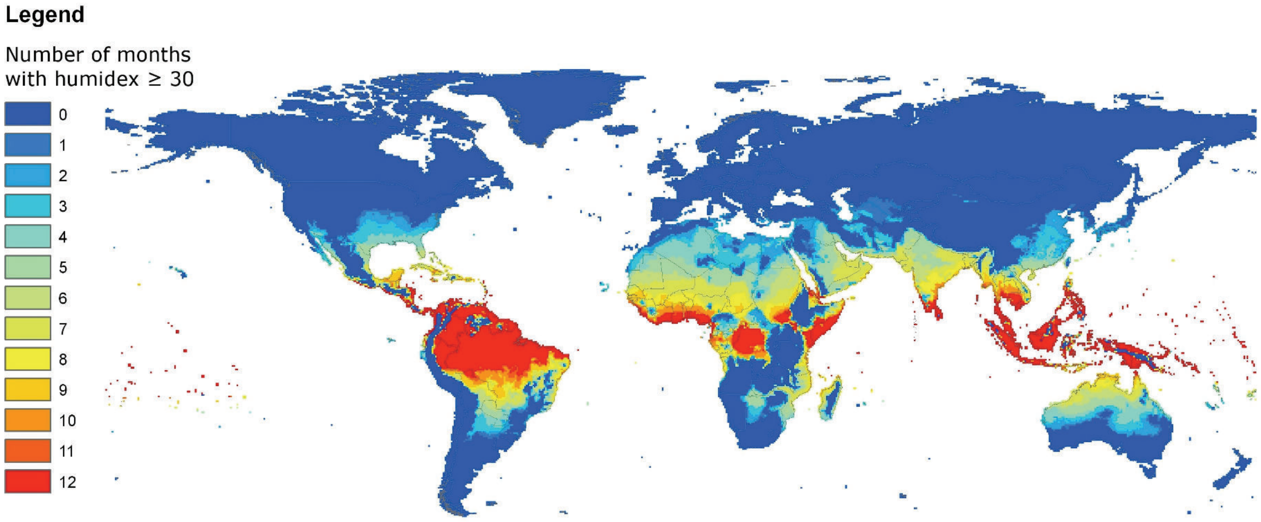

Fig. iii. Map of calendar months with a humidex ≥ 30. *Global map of the calendar months with a humidex ≥ 30, based on the long term average mean monthly temperature and vapour pressure. Temperature and pressure data were taken from [28]. The mean temperature is the average between maximum (reached around 4 PM) and minimum (reached around 7 AM) daily temperature, and is roughly equal to the temperature around 9 PM.*

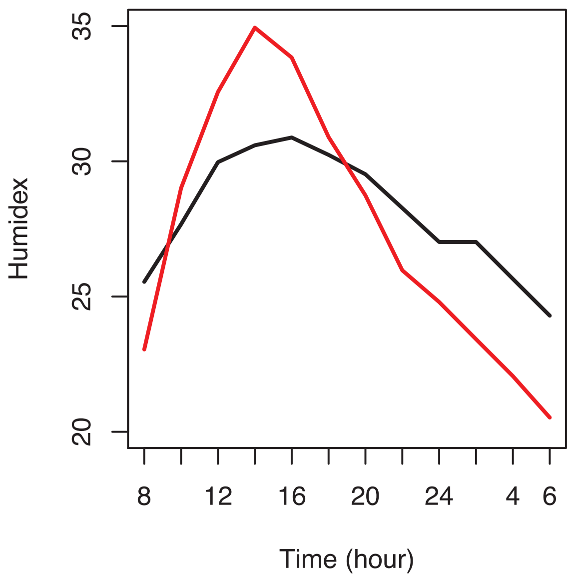

Fig. iv. Diurnal humidex inside and outside traditional houses. *The average diurnal humidex inside traditional houses (black line) and outside in a Stevenson screen (red line) in Kisumu, Kenya, based on data from Haddow [22].*

Table A1 - Factory prices of small solar light kits.

Solar capacity (W)	Battery (number, V, Ah)	Battery Type	Price (US$)
1	3, 1.2, 1	Ni-MH	9.50
1	1, 3.7, 2	Li-Ion	9.80
1.2	5, 1.2, 0.8	Ni-MH	21.00
1.5	5, 1.2, 1	Ni-MH	26.00
2	3, 1.2, 2	Ni-MH	17.50
2	5, 1.2, 2	Ni-MH	23.50
2.5	5, 1.2, 1.8	Ni-MH	33.00
3	1, 6, 4	Lead-Acid	30.80
5	1, 6, 4	Lead-Acid	28.60
5	1, 12, 4.5	Lead-Acid	42.50
6	1, 12, 4	Lead-Acid	49.00

Prices are 2012 quotes from various manufacturers and are for indicative purposes only.