3 Energy requirements in health facilities: a closer look

Classification of health facilities

Types of facilities vary with countries' health systems, socioeconomic development orientation and policies. Classification of health facilities for inventory and analysis purposes has been attempted by various international development agencies (Annex 3). For example, a global survey of medical device availability by country (World Health Organization, 2010a) refers to three to five basic levels of health facility services, most commonly including:

- ***Health clinics/health posts*** cater to primary health needs of communities nearby, offering treatment for the most prevalent diseases (e.g. malaria, TB, HIV/AIDS) as well as maternal and child health services and first response to emergencies. Depending on the country, this level of care may also include special clinics for mother/child care, HIV/AIDS counseling and treatment, or dispensaries to provide anti-retroviral therapy, blood pressure medicine, anti-malarials and TB treatment.
- ***District health centres*** typically offer a wider range of health services to larger populations, as well as some patient beds and more advanced services such as complex obstetric procedures, injury response and diagnosis and treatment of serious infections and fevers.
- ***District, provincial and regional hospitals*** serve larger populations with a more diverse range of services, including more specialized services, surgical centres, intensive care and noncommunicable disease treatment.

Energy needs vary not only in relation to the health facility type, but also in terms of actual services provided, hours of operation, facility size, target population and available equipment. In addition, the range of services offered by primary health facilities, second-tier services, and so on are deeply influenced by external factors such as country-specific needs and priorities, national standards and health budgets.

Electrical equipment required for health services: devices, appliances and infrastructure

Because facilities can offer a wide range of health services, defining energy needs in terms of equipment required has yet to be undertaken systematically. This area requires greater attention by health and energy agencies at global, regional and national levels. However, infrastructure surveys such as SARA do make detailed inventories of equipment available in health facilities, and these surveys can be used as a basis for assessing existing energy needs.

Based on the SARA classification of health services, essential electric equipment and its indicative power requirements can be grouped as: (i) infrastructure, including lighting, communication, water supply and waste management; (ii) medical devices[vi]; and (iii) support appliances for specific health services such as vaccination, infectious and noncommunicable disease treatment, emergency care such as blood transfusions, and surgical services.

Table 3 provides a listing of most of the devices inventoried in the SARA and similar infrastructure surveys. Although energy performance data is not currently a part of the inventory, an indicative estimate of device electricity requirements is presented to illustrate the range and order of magnitude of energy requirements for even basic health facility equipment.

It should be noted that the SARA survey for health clinics and health centres inventories only x-ray devices and a few basic surgical tools, but not more advanced diagnostic and surgical devices. A specialized SARA survey focusing on hospitals, which would include more detailed equipment inventories, is also under development. The *WHO baseline survey on medical devices* also maps current availability by country of seven types of more advanced equipment required for diagnosis and treatment of major noncommunicable diseases such as cancer, as these devices are not widely available in many low-income countries (World Health Organization, 2010a).

The energy requirements denoted in Table 3 provide an indication of the peak demand for power in a facility when many or most devices and appliances are used at one time. However, some devices that consume a lot of electricity may be used intermittently while others may remain on standby power mode for most of the day. Considering all of these factors is important when estimating average daily energy use, particularly if a facility has battery-powered storage capacity so it can store energy from a generator, the grid or a solar power source, and then use that energy at another time.

It is also important to calculate evening and overnight electricity demand, particularly for facilities that rely upon an on-site power source. As previously noted, clinics that are open in the evening may face power shortages when grid power sources fail or are turned off altogether in peri-urban areas so as to channel more electricity to nearby cities.

[vi] A medical device is defined by WHO as an "instrument, apparatus or machine used to diagnose, treat, monitor or alleviate disease or injury. It is also used to prevent disease and compensate for injury." Medical devices thus cover a wide range of products, including syringes, stethoscopes, hip implants, ECG recorders, X-ray equipment, spectacles, dental equipment and virtually any product used specifically for health care purposes that is neither a medicine nor a biological product (*Health Topics: Medical Devices*. 2013. Geneva: World Health Organization, 2013. http://www.who.int/topics/medical_devices/en/).

Table 3. Indicative power requirements of electrical devices for health services[vii]

	Health services	Electrical devices (features and characteristics]	Indicative power rating [W] operation mode	AC power supply	DC power supply or battery port
INFRASTRUCTURE	Basic amenities	**Basic lighting**[1] requirements for **health clinics** are estimated at: ~l62 lux (lumens/m^2), which may be achieved by various types of lamps:			
		✸ Incandescent lamp (~10–15 lm/W)	40–100 W	110/220 V AC	–
		✸ Halogen lamp (~15–20 lm/W)	20–50 W	110/220 V AC	12 V DC
		✸ CFL [viii] (~45–65 lm/W)	10–20 W	110/220 V AC	12 V DC
		✸ LED lamp (~70–90 lm/W)	5–13 W	110/220 V AC	10–30 V DC[3]
		Security lighting, outdoors (LED)	10–100 W[4]	110/220 V AC	10–30 V DC
		Mobile phone battery (charging)	5–20 W[5]	110/220 V AC	5–16.5 V DC
		Desktop computer[ix]	15[6]–200 W[7,8]	110/220 V AC	8–20 V DC[9]
		Laptop computer	20–60 W	110/220 V AC	12–20 V DC[10]
		Internet (V-Sat connection)	85–500 W[11]	110/220 V AC	15–24 V DC[12]
		Printer, ink jet	65[13]–100 W[14]	110/220 V AC	12–20 V DC [15]
		Printer, laser	150–1100 W[16]	110/220 V AC	
		VHF radio receiver: Stand-by Transmitting	2 W[17] 30 W[18]	110/220 V AC	12 V DC
		Ceiling fan (AC)	30–100 W[19,19a]	110/220 V AC	–
		Ceiling fan (DC)	28 W[20,21,22]		12 V DC
		Refrigerator, 165 L (for food & water) (AC)	150–200 W[23,x]	110/220 V AC	–
		(DC)	40–80 W[24,xi]	–	12 V DC
		Portable electric space heater	1392–1500 W[25]	110/220 V AC	48 V DC
		Portable air conditioner (AC & DC variants)	1000–1500 W	110/220 V AC[26]	48 V DC[27]
	Processing of equipment for reuse	Countertop autoclave (steam sterilizer) (19–45 L)	1200–2850 W[28,29]	110/220 V AC	–
		Dry heat sterilizer	500 W[30]–1.56 kW[31]	110/220 V AC	–
	Health-care waste management	Small waste autoclave (35–178 L)	2–6 kW[32]	220 V AC[xii]	–
		Autoclave grinder	1400 W	–	–
		Small water pump – clinic	50–200 W[33]	–	15–30 V DC
		Water pump – district health centre	400–1000 W[34]	110/220 V AC	–
		UV water purifier	10–40 W[35,36]	–	12 V DC
		Reverse osmosis/other water purifier	264 W[37]–570 W[38]	110/220 V AC	–
SPECIFIC SERVICES	**General outpatient services**	Micro-nebulizer	2.5[39]– 36 W[40]	100–240 V AC	9–12 V DC
		Nebulizer	80–90 W[41]	110/220 V AC	–
		Oxygen concentrator[42]	270–310 W 70 W	110/220 V AC	 12–18 V DC
		Pulse oximeter Pulse oximeter (AA battery-operated)	50 W[43] 2–3 W[44]	110/220 V AC	 1.5–3 V DC

Continues…

[vii] Note: This table does not consider electricity demands for dentistry services, which also are important to primary health-care, and deserve further consideration in the energy context. All values are calculated for use in the "active" mode unless otherwise stated. Total daily power consumption (Wh/day) would normally be a function of watt hours of active use plus any standby power requirement. Wherever possible, indicative power requirements have been compiled from data contained in reports and supply catalogues offered by recognized UN or national health and energy research agencies, including: (UNICEF, 2014; World Health Organization, 2013c; United States Agency for International Development, 2012; African Renewable Energy Access Program, 2010; National Renewable Energy Laboratory, 1998). References to other indicative values are noted individually in Annex 4. Reference to performance specifications of specific products or manufacturers does not imply any endorsement or recommendation by the World Bank or WHO, or that they are preferred to others of a similar nature not mentioned.

[viii] Note: Regarding lighting options: Incandescent bulbs are very inefficient and generate a lot of heat. Such lamps are progressively being banned in some countries. CFLs contain volatile mercury and should be avoided when a strong recycling service is not in place. In addition, CFLs produce electromagnetic and UV emissions. Thus whenever possible, LED is preferred. Linear fluorescent tubes, common in developed-country health facilities, have an additional problem insofar as they break easily in settings with electrical perturbations that occur frequently in the unstable grids of developing countries. As an alternative to fluorescent tubes, LED tubelights (9–18 W) with dimming option and running with both AC and DC power are now available in the market.

[ix] Note: Power varies widely for desktop computers, from 15 W for very efficient, new models, plus another 15 W for the monitor display, and up to 200 W for older ones.

[x] Daily electricity requirement for AC refrigerator: 600 Wh–1.44 kWh at ambient temperature of 21.1–32.2° C

[xi] Daily electricity requirement for DC refrigerator: 77–168 Wh at ambient temperature of 21.1–32.2 C°

[xii] Larger models or models with faster cycles often require 440 VAC.

SPECIFIC SERVICES

Health services	Electrical devices (features and characteristics)	Indicative power rating [W] operation mode	AC power supply	DC power supply or battery port
Antenatal, child and adolescent health	**Vaccine refrigerator** (polio, measles, DPT-Hib+HepB, BCG & tetanus toxoid)[xiii] designed to perform at 43° C:			
	Vestfrost VLS200 AC (electric mains) refrigerator, 100 litres (WHO/PQS: E003/031)	115 W[45 xiv]	110/220 V AC	N/A
	Dometic TCW 3000 DC (solar-charged, battery-driven) vaccine refrigerator, 110 litres (WHO/PQS-E003/008)	250 W solar array[46 xv]	N/A	12/24 V DC
	Sure Chill BLF100 DC (solar direct-drive) vaccine refrigerator, 99 litres (WHO/PQS: E003/019)[47]	370 W +/- solar array[xv]	N/A	12/24 V DC
Obstetric and newborn	LED light for phototherapy treatment of neo-natal jaundice[48]	440 W	110/220 V AC	–
	Suction apparatus[49]	90–200 W 33 W	110/220 V AC	 ± 12 V DC
	Vacuum aspirator or D&C kit[50]	36–96 W	110/220 V AC	± 3–6 V DC
	Neo-natal incubator	800–1035 W[51,52]	110/220 V AC	–
	Neo-natal infant warmer[53]	125/550 W[54]	110/230 V AC	–
	Fetal heart monitor (Doppler)	1.5–3 W (AA battery)[55,56]	–	1.5–3 V DC
	Ultrasound	800–1000 W[57]	110/220 V AC	–
	Portable ultrasound	6 W (idle) – 22–28 W (active-charging)[58,59,60]	100–240 V AC[61]	11–15 V DC[62]
General diagnostics, blood analysis and laboratory equipment	Laboratory refrigerator	60–160 W[63,64] 40–80 W (165 L)[65]	110/220 V AC	 12/24 V DC
	Centrifuge	250 – 400 W (low-medium speeds)[66]	110/220 V AC	–
	Mini-centrifuge	25 W[67]	–	12 V DC
	Haematology analyser	230–400 W[68,69]	–	–
	Blood chemistry analyser	45–88 W[70,71]	–	–
	Blood chemistry analyser (hand-held)[72]	–	–	18 V DC battery[73]
	CD4 counter	200 W[74, 75]	110/220 V AC	12 V DC
	Brightfield white light microscope (with LED light)	20–30 W[76]	110/220 V AC	3–6 V DC
	LED microscope (for fluorescence smear microscopy (halogen or LED light)[77,78]	70 W[79,80]	110/220 V AC	12 V DC
	Mercury/xenon fluorescence microscope[81,82]	75–200 W	220–240 V AC	–
	X-ray machine[83 xvi]	15–20 kW	120 V AC	–
		30–40 kW	1Φ/108–230 V AC	–
		50–80 kW	3Φ/400–480 V AC	–
	Portable X-ray machine	3–4 kW[84,85]	90–264 V AC	
	Laboratory incubator	200 W[86]	110/220 V AC	12 V DC
	Vortex mixer	18 W[87]	90/220 V AC	6 V DC
		70–90 W[88]	120/230 VAC	–
TB diagnosis	Sputum-smear microscopy (LED microscope w/fluorescent smear)[89]	30 W (+ 6 W LED bulb)[90] 20–30 W[91,] (+6 W LED bulbs)	110/230 V AC –	– 6 V DC
	GeneXpert MTB/RIF diagnostic	190 W[92,93]	110/220 V AC	12/24 V DC
HIV diagnosis	ELISA test reader	500–650 W[94]	110/220 V AC	48 V DC
Cardiovascular diagnosis/ treatment	Portable electrocardiograph (ECG)	1.2 W[95]–45/70 W[96]	100/240 V AC	3–12 V DC
	Defibrillator with ECG	130–200 W[97,98]	110/220 V AC	14–15 V DC
		100–130 W[99]	–	11.1 V DC
Diabetes	Blood glucose monitor	<1 W	–	3.3–5 V DC[100]
Basic surgical services[xvii]	Suction apparatus (AC)	90–200 W	110/220 V AC	–
	Suction apparatus (DC)	33 W	–	± 12 V DC
	Anaesthesia machine	1440 W[101]	110/220 V AC	
	Low-energy anaesthesia machine with DC monitor backup[102]	480 W – oxygen concentrator 20 W – monitor[103]	220 V	12 V DC backup (for monitor)

xiii Note: Vaccine refrigerators are designed to keep vaccines in a stable +2° C – +8° C range; vaccine cold packs require freezers.

xiv Note: In a well-designed refrigerator, the cooling compressor only operates intermittently so total daily demand would be estimated at about 710 Wh/day

xv At solar radiation reference period average = 3.5 kWh/m²/day – (approximating average solar radiation in less-than-optimal sunlight, e.g. cloudy, rainy and cool-weather days).

xvi These values refer to the power supply for the x-ray generator; 150 kVp is the maximum voltage across the x-ray tube itself.

xvii Including basic procedures such as: tracheotomy, tubal ligation, vasectomy, dilatation and curettage, obstetric fistula repair, episiotomy, appendectomy, neonatal surgery, skin grafting, open treatment of fracture, amputation, cataract surgery. Note: Dental surgery procedures can impose significant load requirements including: dental compressor (~750 W-2.2 KW); dental sterilizer (~850 W); and dental chair & exam light (200 W); as well as x-ray and other specialized devices.

Table 4 illustrates a simplified example of how average daily demand for power can be calculated in more detail. It has been excerpted from real-life experience in planning the power needs for an off-grid health research facility in Liberia (Kuesel, 2013). Simple spreadsheet tools permitting even more sensitive hour-by-hour load calculations also are available online and described further in Annex 4 (United States Agency for International Development, 2012). These can more precisely assess energy needs during peak load times, as well as energy use at all hours.

Table 4: Example of an average load calculation using selected medical equipment*

Application	Qty.	Unit power consumption [W]	Total power consumption [W]	Hours of use daily	Days used in a week	Mean energy [Wh/day]	Share of total daily consumption	Day	Night	Daytime Wh	Night Wh
Laptop computer, Dell 630 1	1	160	160	8	7	**1280**	3.29%	80%	20%	1024	256
Photocopier/scanner	1	1200	1200	1	7	**1200**	3.09%	80%	20%	960	240
Mobile phone charger for ~15 phones (15 pieces counted as 1)	1	5	5	24	7	**120**	0.31%	80%	20%	96	24
DC electrocardiograph (ECG) 1	1	25	25	4	5	**71**	0.18%	80%	20%	57	14
Freezer, Kirsch Frostex (96 L) #2	1	160	160	6	7	**960**	2.47%	50%	50%	480	480
Refrigerator, Kirsch Labo (100 L) #1	1	150	150	3	7	**450**	1.16%	50%	50%	225	225
Peak power consumption (W)			**1700**								
Mean daily power consumption (Wh/Day)						**4081**					
Mean daytime power consumption										**2842**	
Mean night-time power consumption											**1239**

* This analysis presumed a single 230 Volt AC (VAC) power supply for all appliances (and including use of AC converters for connecting DC devices). A more complete assessment would also consider energy efficiency strategies to reduce demand and optimize power system design.

Improving energy efficiency of medical devices and appliances

Whereas traditionally, energy efficiency was not a primary objective in the design of medical devices, today the trend is towards higher efficiency and greater portability. For example, mercury-lit microscopes that consumed large amounts of energy were, until recently, the state-of-the-art equipment for certain procedures such as TB fluorescence smear microscopy, which is important for TB diagnosis in low-income countries. Mercury-lit microscopes are being rapidly replaced by ultra-efficient LED-lit microscopes that are more robust and reliable and can be operated using batteries or PV solar sources (Hanscheid, 2008; World Health Organization, 2010b). Similarly, conventional diagnostics using enzyme immunoassays (e.g. ELISA) require a reliable electricity source for test incubators as well as intermittent electricity access for analysis (World Health Organization and UNAIDS, 2009). Yet rapid tests that require little or no energy have become increasingly robust and available at primary health care level for malaria, HIV/AIDS, congenital syphilis and some vector-borne diseases.

The constant emergence of new technologies also means power requirements of different designs may vary widely, including across AC and DC variants of the same device. AC is the traditional current provided by the grid or generators for which most heavy electric appliances were originally developed. There is, however, an increasing array of portable and digital devices designed to use low-voltage DC power supplied by batteries and PV solar systems. Such devices include vaccine refrigerators, many of which have been WHO-reviewed and "prequalified" (World Health Organization, 2013d), battery-operated blood glucose monitors, LED-lit microscopes for TB diagnosis, digital pulse oximeters to measure blood oxygen levels, and sphygmomanometers which are blood pressure measurement devices (Parati et al., 2010; World Health Organization, 2010b). There are also low-power fetal heart monitors, ultrasound and medical suction devices to monitor and assist women in childbirth.

Many electronic devices (phone chargers, computers, etc.) are inherently DC-designed devices. Digital and semiconductor technologies that originated with information technologies and telecommunications stimulate medical device innovation, including more low-energy devices that can run on batteries and solar panels (Aronson, 2012). Frequent review of available technologies and devices is needed to determine energy requirements for health service delivery and inform a demand-driven approach to energy access. Table 3 provides indicative examples of devices that are powered by AC and DC technologies, along with their respective energy requirements.

Thermal energy needs of health facilities

In addition to electricity, health facilities may use thermal energy for cooking, water heating, space heating, sterilization and medical waste incineration, as well as for cooling in applications such as absorption refrigeration (using LPG or kerosene). Thermal energy may be produced through direct combustion of fuel (e.g. stove or boiler use of biomass, gas, kerosene or diesel). In settings where electricity is abundant, some or all thermal energy needs may be met with electric-powered stoves, water heaters, etc.

Health facilities use steam for purposes such as air humidification, equipment sterilization and hazardous health care waste disinfection (autoclaving). A recent landscape analysis covering 21 developing countries found that only 56% of facilities had access to adequate sterilization equipment; analysis across 16 countries found that only 59% of health facilities had adequate disposal systems for hazardous waste (World Health Organization, 2014).

Hot water can also be useful for hygiene (e.g. bathing), kitchen sanitation, laundry and other cleaning, supporting reduced nosocomial infection transmission between patients or patients and staff. Hot water, or steam, can also be used for space heating.

Large hospitals may produce hot water and steam from central boilers, municipal district heating systems or on-site CHP sources, although electric boilers and electric autoclaves are also common for point-of-use steam generation, particularly in smaller facilities (Emmanuel, 2012). This can make steam production costly as well as polluting. Solar thermal or solar photothermal-powered autoclaves that generate steam have been tested and validated in field and laboratory settings by Rice University (Neumann et al., 2013) and MIT's Innovations in International Health platform (Kaseman et al., 2012). These use forms of concentrated solar power or broadband light-harvesting nanoparticle technologies to achieve temperatures sufficient for small-scale medical equipment sterilization and reuse, although not for larger-scale waste management. More conventional passive solar thermal water heating systems are becoming more common in both developed and developing countries, and can usually heat water to a temperature suitable for basic hygiene and sanitation.

Space heating is important in health facilities in temperate climates, and during the cold season of higher-altitude zones of Central Asia, Latin America and Africa, as well as the Mediterranean. Exposures to cold or dampness increase the likelihood of asthma, allergies and acute respiratory diseases (Wu et al., 2004; World Health Organization, 2011; World Health Organization, 2012a). Space heating in developing-country facilities may be provided by district heating, electricity or on-site fuel-based solutions. Thermal solar "combi-systems" that heat both water and space are increasingly being used in Europe, China and the Middle East (World Health Organization, 2011).

Avoiding excessive overheating – particularly in sensitive wards, operating theatres and laboratories – is likewise a particular concern in mild, arid and tropical climates. Improving building thermal performance with significant passive cooling can help accomplish this using careful building orientation, shading, and natural or mechanically supported natural ventilation.

As both space heating and air conditioning are often energy-intensive applications resulting in high expenses, improving buildings' energy efficiency through use of window placement, day lighting and passive solar strategies can reduce heating and air conditioning requirements. Use of natural ventilation can also help reduce transmission of airborne infectious diseases, particularly tuberculosis (Atkinson et al., 2009).

Together with the use of climate-adapted materials for roofing, walls and insulation, passive cooling strategies can reduce reliance on energy-intensive air conditioning systems while saving significant long-term energy costs. In modern buildings, the energy savings can amount to 30–50% or even more (Levine & Urge-Vorsatz, 2007; Kapoor & Kumar, 2011; Bonnema, 2010). Recently, some large modern facilities have been designed in Africa and Asia using indigenous building materials (e.g. local brick and stone) that are more climate-adapted than mass-produced concrete blocks (Partners in Health, 2011). While there are many contextual factors to consider, such as structural safety and resilience, use of energy-efficient building materials can significantly improve thermal conditions and save energy and expense compared with conventional materials. Along with cost savings, reducing mechanical space cooling and heating requirements allows available heat and power supplies to be allocated to medical interventions. Such energy efficiencies are receiving increasing interest and uptake among health facilities worldwide (Box 2).

Thermal energy is frequently used for medical waste incineration. Poor management and unsafe disposal of medical waste can threaten patients, communities and medical staff. Developing countries have limited options for safe health care waste disposal. Dumping untreated infectious waste in landfills can create health risks for scavengers and cause local environmental damage. Contaminated sharps,[xvii] in particular, are a source of injury and infection risks. At the same time, waste incineration in open pits or single-chamber combustion incinerators – the methods most common today in many low-income countries – creates other serious health risks through the airborne emission of dioxins and furans as well as the creation of hazardous solid waste residues (Chartier Y et al. 2014).

As a result, WHO recommends that infectious and noninfectious waste be separated at the source to reduce the hazardous waste stream as much as possible. This also facilitates recycling of certain kinds of non-infectious waste, e.g. cartons, and composting of kitchen waste where feasible.[xviii]

For infectious medical waste, WHO also recommends that wherever possible, infectious waste undergo microwave or autoclave disinfection or sterilization, rather than incineration. This may be followed by grinding to reduce the volume of waste that needs landfill disposal. WHO and the United Nations Development Programme also are testing new ways to safely reprocess sterilized plastic, glass and metal in a project supported by the Global Environment Fund (Global Environment Fund, 2013). Non-incineration management of medical waste, however, requires considerable electricity. As such methods become more widespread,

xvii "Sharps" is a health sector term referring to sharp objects such as needles, blades, scalpels and other items that can break the skin; sharps can also include broken glass items such as Pasteur pipettes and blood vials. Used syringes and tubes connected to sharps are also typically regarded as infectious waste.

xviii Biodegradable waste (e.g. paper and food scraps) and solid-waste sewage also can be processed using anaerobic digestion to generate biogas energy.

Jimma, Ethiopia: *Hospital staff cook over a wood fire. Cleaner stoves and fuels can reduce exposures to indoor air pollution. (Photo: WHO)*

their power needs will also have to be considered in health facilities' electricity budgeting.

Particularly in energy-constrained settings, successful development of reliable energy systems thus requires careful assessment of all aspects of health facility energy needs. Electricity needs, which are the focus of this report, are typically calculated in terms of average daily (kWh) and daily peak (kWp) loads, as well as day-time and night-time variants.

Certain building energy needs vary seasonally, especially for heating and cooling. The presence or absence of energy-efficient building design features such as day lighting, ventilation, insulation and passive solar design also profoundly affect energy loads required for lighting, cooling and heating. Foreseeable load increases to serve additional energy needs in the near future also need to be considered in the facility's load profile. Procurement of more or less energy-efficient medical equipment will influence the future load profile, as will energy-saving retrofits to the building itself.

On the supply side, key considerations include the power capacity that can be provided by various sources as well as their reliability and all capital and running costs – whether the primary supply source is the grid, off-grid or hybrid. Daily, as well as seasonal, peaks and gaps in energy demand and supply also are critical factors. For instance, there may be interruptions in grid electricity supply especially during the evening peak, or seasonal variations in solar or wind power production, or interruptions in fuel deliveries when roads become impassable. These variables are considered further in the next chapter.

Box 2. Energy efficiency in building design and management

India's energy-efficient Bhopal Sambhavna Clinic is designed with double external walls, including a perforated shell called *jaali*, to deflect the sun's rays while allowing daylight to penetrate. This green facility provides medical care to survivors of the 1984 Union Carbide chemical leak, one of the world's worst incidents of industrial chemical poisoning (Stephens, 2006; Guenther & Vittori, 2007). A similar double-wall approach is used in Susques Hospital, Argentina (Hernández et al., 2010). Space between outer and inner walls enhances building cooling, while large windows as well as ceiling fans and vents provide more air exchanges than in comparable air-conditioned buildings.

Rooftop pools (Jain, 2006), evaporative cooling systems (Hindoliya & Jain, 2010) and cooling courtyards (Safarzadeh & Bahadori, 2005) are other common passive solar techniques receiving serious attention among building researchers and designers. Energy required for lighting can also be reduced significantly with effective use of daylight (Levine, 2007). In Nguru, Nigeria, a nursery for newborns was redesigned to reduce energy by lowering floors 120 cm below ground, raising roof heights, creating double walls, placing new windows for cross-ventilation and adding window blinds. Air conditioners that had frequently ceased operation due to power cuts were replaced with a solar-operated roof extractor fan and a flowing water heat exchanger. Between January and July 2013 these measures kept indoor ambient temperatures stable below 33.5° C, while in a "control" nursery temperatures rose as high as 39.5° C on peak-heat days of 45–46° C outdoors. These interventions reduced risk of neonatal hyperthermia, referred to as evening fever syndrome, which is a common but rarely studied condition affecting morbidity and mortality of newborns in hot climates (Amadi et al., 2014).

Modeling of alternative strategies can allow engineers to determine which work best in different thermal conditions. For instance, a study on passive cooling of cement-based roofs in tropical climates found that fitting a corrugated aluminum sheet, specially angled to dissipate heat, and overlaying another sheet of insulation to minimize heat transfer could reduce thermal heat load by 70% as well as regulate thermal fluctuations (Alvarado, 2008). In China, porous wall tiles have been studied regarding their cooling effects on buildings (Luo et al., 2009). Similarly, a concrete roof insulated with a layer of vermiculite and covered by tiles was part of a model Indian facility's energy-efficiency plan. Hareda, a community health centre, used vegetation and window orientation as well as layers of roof and wall insulation to shield the clinic from radiant heat. Evaporative cooling systems also helped reduce indoor temperatures from an average of 40° C to 30° C (Shukla, 2009).

Energy management strategies are equally important and can range from complex computer-controlled systems to very simple sensor-powered lighting, water taps with automatic shut-off valves, and user training to turn off appliances such as computers when not in use. Energy efficiency should receive higher priority in facility design, planning and management to allow health services in energy-poor countries to "move up" the energy ladder most inexpensively and efficiently.

Butaro District Hospital, Rwanda: Airy, open-air waiting areas reduce infection risks as well as facilitating community interaction in an energy-efficient hospital developed by the Rwanda Ministry of Health along with Partners In Health.

Butaro District Hospital, Rwanda: Patient beds face a window, so healing mothers have a view of nature, while ceiling fans affixed to the high ceilings support cooling and fresh air circulation. (Photos: MASS Design Group)