sixteen

Summary and Conclusions

In this chapter, tables categorizing and summarizing the technologies available to reduce energy use in buildings, summarizing all quantitative references in this book to energy savings potential, and summarizing all quantitative references to costs are presented. We then return to the question that motivates this book: Can energy use in new and existing buildings be reduced to levels low enough, in the context of future population growth and in the growth of floor area per capita, such that the remaining energy use can eventually be met by renewable sources of energy? In other words, is sustainability in the buildings sector feasible?

16.1 Summary of technologies, development status and applicability

Table 16.1 summarizes the design features, technologies and systems available to reduce energy use in buildings that have been discussed in this book. These have been categorized into the following broad categories:

- simple and well understood, primarily architectural decisions;
- simple and well understood, pertaining to mechanical systems and lighting;
- moderately complex.

These categories have been further divided into zero-to-low cost, low-to-moderate cost, or moderate-to-high cost, either with partially to entirely offsetting savings in mechanical equipment through downsizing, with attractive payback periods in spite of high initial cost, or without attractive payback periods except in special circumstances. The vast majority of the technologies and techniques listed in Table 16.1 already exist and have been used successfully in at least one or more countries, although some very promising techniques – such as liquid desiccant dehumidification systems for hot-humid climates, advanced daylighting systems, building-integrated photovoltaics, solar-assisted district heating, and solar-driven cooling systems require further development to bring down costs and to improve performance.

Table 16.1 Summary of design features, technologies and systems available to reduce energy use in buildings. Items have been subjectively classified as simple and well understood, or moderately complex and further classified according to capital cost. High-cost items are classified here as 'cost-effective' if they represent the lowest-cost choice on a lifecycle basis

Simple and well understood, primarily architectural decisions			
	Conventional, applicable everywhere		
		Zero-to-small cost	
			• Building form, shape, glazing area and shape on each façade, and choice of operable instead of fixed windows: Impacts heating load and cooling load through impact on solar heat gain and on surface-area: volume ratio. Impacts opportunities for passive ventilation and daylighting. Optimal choices depend on type of building, occupancy pattern and climate. Requires simple analysis tools for optimization of these choices. • Choice of high-reflectivity (low albedo) building envelope to minimize summer cooling requirement • Upgraded construction details to reduce air leakage through the envelope
		Low-to-high cost, partly to entirely offset through savings in mechanical systems and/or other benefits	
			• Insulation (provides heating and/or cooling benefits, depending on climate, and peak load benefits) • High-performance windows (low heat loss coefficient to reduce heating requirements and/or low solar heat transfer to reduce cooling requirements, depending on climate) • Thermal mass (to maximize use of solar heat in winter and the benefit of night-time ventilation in summer where this is useful) (less applicable in hot-humid climates due to smaller diurnal temperature range) • Fixed external shading devices (applicable to equatorward-facing walls) • Adjustable external shading devices (manual or automatic, most useful on east- and west-facing walls) • Simple design features (beyond building form) to facilitate passive and hybrid ventilation (trickle ventilators, wider air ducts, internal airflow pathways)
	Unconventional, widely applicable		
		Low-to-moderate cost, often with quick payback	
			• Evaporative cooling (commercial products available in some markets, but requires further development of commercial products everywhere; not applicable in hot-humid climates unless combined with desiccant dehumidification; not applicable in hot-arid climates with severe water shortages, where night ventilation with thermal mass is often effective)
		Moderate-to-high cost, partly to largely offset through savings in mechanical equipment	
			• Earth pipe cooling (less applicable where ground temperature and peak summer temperatures differ little)
Simple and well-understood, pertaining to mechanical systems and lighting			
	Modest additional capital cost with short payback times		

			• Variable air volume ventilation systems instead of constant air volume systems • Variable-speed drives on all pumps and fans • Variable-speed (modulating) air conditioners and chillers • Basic hydronic heating and cooling (2-pipe or 4-pipe systems with fan coils) to separate heating, cooling and ventilation requirements • Heat recovery between fresh air and exhaust air • Basic automation systems (such as shutting off or reducing heating, cooling and ventilation when not needed) • High performance but fully electric lighting systems
	Simple (because packaged), expensive in most jurisdictions due to immature markets, potentially or already cost-effective on a lifecycle basis		
			• Condensing furnaces and boilers • Condensing combisystems for integrated space heating and domestic hot water • Domestic and small commercial biomass boilers
Moderately complex			
	Well developed, widely used in some jurisdictions		
		Modest or no net capital cost when properly integrated into the building design	
			• Advanced design features to facilitate passive ventilation (solar chimneys, wind cowls) • Displacement ventilation • Chilled-slab heating and cooling • Dehumidification using solid desiccants • Demand-controlled ventilation system and other more advanced control systems • District heating and cooling systems (no net capital cost possible compared to heating and cooling plants in individual buildings)
		Modest-to-large capital cost, but cost-effective in many jurisdictions	
			• Solar thermal collectors for domestic hot water • Transpired solar collectors for preheating ventilation air • Ground source heat pumps
	Requiring further development and refinement through practical demonstration		
		Potentially low-cost	
			• Liquid desiccant dehumidification (overcomes limitation of evaporative cooling in hot-humid climates) • Simple daylighting systems (involving simple components such as light shelves, passive light pipes, or sun-reflecting glass) (cost and complexity arise through controls, sensors and dimmable ballasts in the electric component, and in automatic control of shading devices) • Diurnal storage of coldness using eutectic salts (storage with ice is well established and cost-effective, but unlike eutectic salts, is not suited for high temperature (16–20°C), efficient displacement ventilation and chilled ceiling cooling systems)
		Likely to remain high cost but potentially cost-effective in some jurisdictions	
			• Advanced glazing (electrochromic and thermochromic windows) • Transparent insulation • Double-skin façades • Advanced daylighting systems (such as light pipes with sun-tracking reflectors) • Solar-powered absorption, adsorption or ejector chilling • Solar-powered desiccant (solid or liquid) dehumidification and cooling • Building-integrated PV panels • Solar cogeneration • Seasonal underground storage of thermal energy (solar, or from cogeneration)

16.2 Summary of energy savings potential

Table 16.2 summarizes the quantitative references to energy savings potential that are found in this book, along with the section where each reference is found. All of the technologies listed in Table 16.2 already exist and their performance has been measured in numerous field tests. Envelope measures alone can reduce heating requirements in both residential and commercial buildings by up to 90 per cent, while envelope measures combined with passive ventilation or combined with night ventilation and thermal mass can frequently reduce energy requirements for cooling and ventilation by 75 per cent and can sometimes eliminate these energy uses altogether. Many individual HVAC measures can reduce HVAC energy use by 25–50 per cent, a savings that would be applied to the reduced loads created through envelope measures. Low-energy cooling techniques in one form or another (night ventilation combined with thermal mass, earth pipe cooling, evaporative cooling, desiccant cooling) are applicable under almost any climatic conditions that are encountered almost anywhere in the world, including both hot-arid and hot-humid climates. Advanced electric lightings systems have frequently achieved 50–75 per cent reductions in lighting energy use compared to typical recent practice in new buildings in many jurisdictions, with further savings through advanced daylighting systems.

Table 16.2 Summary of most references to energy savings potential in this book.

Item	Savings potential	Section
Chapter 3, Thermal Envelope		
Structural insulated panels	50% reduction in heating energy use compared to standard US housing	3.2.3
Dynamic insulation	Up to a factor of eight reduction in effective U-value	3.2.4
Attic low-e foil	25–50% reduction in heat flux, 7–10% reduction in cooling load in US SE	3.2.9
Advanced insulation systems	Provide 2–3 times the resistance to heat loss as conventional insulation systems in most jurisdictions	3.2.10
High-performance windows	As little as 1/5 the heat loss of non-coated double-glazed windows, serving as a net heat source in winter in most climates for most orientations	3.3.6 and 3.3.12
High-performance windows	SHGC as low as 0.23 with visible transmittance of 0.41	3.3.10
High-performance curtain wall, glazed portion	70% reduction in heat loss compared to ASHRAE 90.1-2004 in 4500 HDD climate	3.3.18
Vacuum insulated panels in curtain wall spandrel (opaque) sections	Factor of 4–8 less heat loss compared to ASHRAE 90.1-2004 in 4500 HDD climate	3.3.18
High-performance glazing + radiant slab heating and cooling in Vancouver buildings with 50% glazed wall area	45% savings in total energy use	3.3.20
External shading devices	Reduce heat gain by 90% (compared to 50% by internal devices)	3.4.2
Vacuum insulated panels in doors	30% less heat loss for complete door system compared to door with conventional insulation, and 65% less heat loss compared to a 6cm thick wood door	3.6
Air leakage, residential	Factors of 3–30 less leakage achieved in housing through quality construction, compared to average practice, depending on location	3.7.1
Air leakage, commercial	Factor of 6–8 difference between modestly good practice and typical practice of some countries	3.7.2

Chapter 4, Heating Systems		
Solar air collectors	Can meet 80% of annual heating load in well-insulated buildings with collector area equal to 16% of floor area	4.1.3
Airflow windows	60–75% reduction in effective U-value	4.1.7
Furnace efficiency	70–97% (up to 28% savings)	4.2.1
Boiler efficiency, full load	68–95% (up to 28% savings)	4.3.1
Boiler efficiency, part load	Can be as little as half the full-load efficiency at 25% of full load	4.3.2
On-site cogeneration	62–78% overall efficiency, 45–65% marginal efficiency of electricity generation	4.6.1
Chapter 5, Heat Pumps		
GSHPs	Can save 25–65% in heating energy and about 35% in cooling energy compared to ASHPs	5.3.2
Reduction in heat-distribution temperature (through envelope improvements) so that condenser temperature can be reduced from 60°C to 40°C	25–30% energy savings for an evaporator at −15°C to 0°C	5.5
Increase in chilled-water temperature (through alternative system design) so that evaporator temperature can be increased from 0°C to 10°C	25–30% energy savings for a condenser at 30°C to 40°C	5.5
Heat pumps with CO_2 as a working fluid	Slightly lower COP for cooling, slightly higher COP for heating if fully optimized	5.8.1
Integration of heating and cooling loads in a sports and health complex, Mexico	38% savings in thermal energy	5.12.1
Chapter 6, Cooling Loads and Cooling Devices		
Building-scale voids and double-skin roofs and façades	Can reduce cooling load by up to 50% in Okinawa (latitude 26°N)	6.2.1
White reflective roofs	Reduce cooling loads by 20–25% in Florida and 20–40% in California	6.2.2
Shade trees + higher albedo roofs and roads	50–60% savings in cooling energy use in Los Angeles	6.2.2
5cm of polystyrene roof insulation	Reduce cooling load by 45% in Cyprus	6.2.3
10cm of roof and wall insulation	Reduce cooling load by 14% in Tehran (and heating load by 55%)	6.2.3
Raising insulation from false ceiling to roof	5–10% savings in annual cooling load in California (and 20–25% reduction in peak load)	6.2.3
Insulation on external and internal walls in Hong Kong apartments	40% reduction in annual cooling energy use	6.2.3
Thermal mass combined with passive night ventilation	100% reduction in cooling loads in locations with cool nights; negligible reduction in Hong Kong but 30–40% reduction in peak cooling loads	6.2.6
Double-skin façades (DSF)	Can reduce solar heat gain to as little as 2.5%	6.3.2
DSF with passive daytime and night-time ventilation	About 80% reduction in primary energy used for heating, sensible cooling and ventilation energy for south-facing façades in The Netherlands	6.3.2
Thermal mass combined with mechanical night ventilation	30% net energy savings for optimized buildings in the UK and in Kenya during the hottest month	6.3.3
Evaporative cooling	92–95% savings in California homes	6.3.7
Evaporative cooling from roofs	73% reduction in cooling load, 66% reduction in fan energy in California; 52% reduction in cooling load in Iran	6.3.7
Earth pipe cooling	Cooling COPs of 5–8 over a range of sites	6.3.8
Residential air conditioners	Best Japanese models twice as efficient as typical North American and European models	6.4.1

Rooftop air conditioners	Most have at least one operational deficiency that can save 25% if corrected	6.5.1
Large, centralized chillers	Up to 2–3 times more efficient than window and wall-mounted air conditioners	6.5.2
Variable speed drive on centrifugal chiller	41% annual savings in a Toronto case	6.5.2
Absorption chillers	Can increase or decrease primary energy use	6.6.1
Correct sizing of cooling equipment	Can reduce annual cooling loads by 6–22% in Hong Kong office buildings. Real seasonal COPs of residential air conditioners in the US as little as half the rated COP due to oversizing	6.8
Off-peak cooling	Energy to generate a kWh of electricity 20–43% less at night than during the day in California	6.9.2
Free cooling with cooling towers and chilled ceilings	Cooling tower meets cooling load 67% (Milan) to 97% (Dublin) of the time. COP of 8–20 based on fan and pump energy use. Reduction of annual cooling load by 50% in Key West (Florida) to 85% in Arizona	6.10.2
	Chapter 7, HVAC Systems	
Reduce required airflow by 50%	Reduces fan energy use by a factor of six if duct size is not changed	7.1.2
Loop rather than radial duct design	Reduces fan energy use by 20–25%	7.1.2
Rebalancing pump systems after installation	Up to 25% savings in pump energy use	7.1.3
Proper sizing of pumps	Up to 30% savings in pump energy use	7.1.3
Optimal combination of cooling and dehumidification in the humid tropics	Up to about 20% savings in air conditioning energy use	7.1.4
Furnace air handlers	Up to 93% savings in annual energy use using ECPM motors instead of PSC motors	7.3.2
Heat recovery ventilators	Can recover up to 95% of the heat in ventilation exhaust air, but require proper installation and maintenance	7.3.3
Ceiling fans	75% savings through more efficient motors and aerodynamic blade design	7.3.5
Leaky ducts	Reduce effective COP of air conditioners and heat pumps by 25–40%	7.3.6
VAV instead of CAV systems in commercial buildings	50–65% savings in combined cooling, heating and ventilation energy use in various US cities	7.4.3
Chilled ceiling cooling	6–42% savings in cooling energy use in various US cities compared to all-air systems	7.4.4
Displacement ventilation	40–60% savings in cooling energy use in various US cities compared to a standard VAV system	7.4.5
Demand-controlled ventilation	20–30% savings in combined cooling, heating and ventilation energy use in various US cities	7.4.6
Floor radiant cooling	31% savings in cooling energy use at Bangkok International Airport	7.4.8
Sensible heat exchangers	Recovery of up to 85% of the heat in exhaust air	7.4.9
Heat pipes around air conditioners	15–30% savings (and 25–50% increase in dehumidification capacity)	7.4.10
Solid desiccants	25–30% savings in primary energy use for cooling and dehumidification, 40–50% savings if waste heat or solar heat can be used	7.4.11
Liquid desiccants	15–25% savings in primary energy use for cooling and dehumidification, 40% savings if waste heat or solar heat can be used	7.4.12
Membrane heat exchangers (experimental)	About 25% computed savings for cooling and dehumidification in Beijing, 60% in Hong Kong	7.4.13

Earth pipe loop + cogeneration applied to desiccant dehumidification in Germany	70% savings relative to vapour compression chilling with a COP of 3.0, 56% savings if the baseline COP is 6.0	7.4.14
VAV in laboratories instead of CAV; reduced pressure drop, enthalpy wheel in US cities	24–44% savings in fan + pump + chiller electricity use 62–75% savings in heating energy use	7.4.17
Fume hoods with variable flow (based on occupancy) and design to minimize turbulence	45% savings in a university laboratory in Montreal.	7.4.17
Commissioning	20% savings in total HVAC energy use	7.5
Optimal control settings	20–35% savings in total HVAC energy use	7.5
Chapter 8, Domestic Hot Water		
Water savings fixtures	50% savings in water use	8.2
Condensing, tankless water heater	15% savings in overall efficiency + elimination of standby losses (which account for up to 1/3 of DHW energy use)	8.3.2
Heat recovery	25–35% savings	8.4.2
Residential circulation loop	Saves 80% of the hot water wasted waiting for hot water to arrive at the faucet	8.5.2
School recirculation loop	94% savings in pump energy use through point-of-use water heaters	8.5.3
Chapter 9, Lighting		
Daylighting with dimmers	40–80% savings in lighting energy use in perimeter offices, 20–33% savings in combined lighting + cooling energy use	9.3.3
Advanced lighting (without daylighting)	50–75% savings	9.5.1
Task/ambient lighting	Up to 50% savings	9.5.2
High intensity fluorescent lamps	40% savings in athletic facilities relative to standard metal halide lamps	9.6
Chapter 10, Appliances, Consumer Electronics, Office Equipment and Elevators		
Refrigerator/Freezer units	Almost factor of 2 difference in energy use, best vs worse, within a given size catagory	10.1.1
Freezers	Almost factor of 1.5 difference in energy use, best vs worse, within a given size catagory	10.1.1
Ovens, cooktops	25–35% savings, best vs worse. Within a given size category	10.1.1
Washing machine	80% savings, best front-loading machine vs US standard for top loading machines	10.1.2
Clothes dryer	40% savings due to dryer clothes from front-loading washing machine	10.1.3
Dishwasher	20–35% savings potential	10.1.4
Standby energy use by consumer electronics	60–70% potential reduction at little or no additional cost	10.2
Advanced gearless Elevators	40–60% savings	10.5
Chapter 13, Advanced New Buildings		
Passive houses in Europe and Advanced houses in Canada	75% savings in heating energy use relative to conventional new housing	13.2.1
Modest measures in US houses	50% savings in total energy use	13.2.1
Modest measures in Turkey	60% savings in heating energy use	13.2.1
Integrated design process (IDP) for commercial buildings	35–50 % savings in total energy use compared to conventional new buildings	13.3
IDP combined with advanced features	50–80% savings in total energy use compared to conventional new buildings	13.3

Chapter 14, Retrofits of Existing Buildings		
Simple, cost-effective envelope measures	25–30% savings in old residential buildings	14.1
Extensive retrofits	Up to 90% savings in heating energy and 80% savings in total energy in old residential buildings	14.1
Deep retrofits of commercial buildings	50–75% savings demonstrated in a wide variety of types of buildings in many different countries	14.2
Chapter 15, Community-Integrated Energy Systems		
Simple cycle cogeneration	65–72% overall efficiency, 44–62% marginal efficiency of electricity generation	15.2.6
Combined cycle cogeneration	90% overall efficiency, 88–90% marginal efficiency of electricity generation	15.2.6
Centralized heating	10–20% savings compared to decentralized heating, at least partly offset by distribution losses	15.3.2
Centralized chilling	Up to factor of three improvement in chilling COP, depending on the size and part-load efficiency of decentralized equipment that is replaced, partly offset by distribution losses and pump energy use	15.3.6
Seasonal underground storage of solar energy	Provides up to 95% of annual space heating load	15.5.3
Heating and cooling systems as a wind energy buffer	Can allow wind to supply 50% of total electricity demand with minimal spillage of wind energy	15.5.6

16.3 Summary of costs

Table 16.3 summarizes all references to cost found in this book, along with the section where each reference is found. The cost-effectiveness of envelope measures is dependent on, or greatly enhanced by, savings in the cost of mechanical systems (heating and cooling plants, ductwork, radiators) and associated electrical systems through the downsizing that is possible with a better envelope. In order to realize these savings, a fully integrated and iterative design process is essential. Many high-efficiency measures involving HVAC systems (such as chilled ceiling cooling, displacement ventilation and sensible and latent heat exchangers) also permit downsizing of heating and cooling equipment and of ventilation fans, thereby offsetting some to all of the additional cost of the energy efficiency measures. Promising low-energy cooling techniques, involving enhancement of evaporative cooling with solid or liquid desiccants, have the potential to become competitive with conventional cooling systems on a first-cost basis. Advanced lighting systems involving daylighting controlled dimming remain expensive and require skilled designers and installers, but are still at an early stage of commercialization. Electricity from building-integrated photovoltaic panels (BiPV) is 1.5 to 3 times the average cost of electricity in sunny locations (2200kWh/m^2/year) with favourable financing (i.e. 24–33 cents/kWh) and 3–5 times the average cost of electricity in less sunny locations (1650kWh/m^2/year) with favourable financing (30–45 cents/kWh). However, if costs can be cut in half, BiPV will be competitive with grid electricity at times of peak demand in many locations, and will serve to relieve growing transmission bottlenecks in urban areas by providing electricity where it is needed. Solar thermal energy with seasonal storage is already competitive with conventional heating systems on a lifecycle cost basis in some locations. Solar driven absorption and desiccant chilling systems, on the other hand, are likely to remain expensive unless they can make use of excess solar thermal heat from collectors that are installed primarily to meet winter heating requirements.

Table 16.3 Summary of all references to capital cost (i.e. upfront cost) in this book

Item	Cost	Section
Chapter 3, Thermal Envelope		
Structural insulation panels	Labour savings can offset greater material costs	3.2.3
Vacuum insulation panels	Cost in Switzerland of 320€/m^2 for U = 0.15W/m^2/K panel, compared with 32€/m^2 for comparable fibre or solid-foam insulation. Incremental cost when applied to walls is about (4000€ × window area fraction) per m^2 of saved floor space	3.2.7
Engineered I-beams	Lack of warping and shrinking, eliminating backing and callbacks to fix popped nails, can offset greater material costs	3.2.10
Electrochromic windows	\$1000/m^2 in 2000, expected to drop to \$100/m^2 with large-scale manufacturing, not including control costs	3.3.15
Components of high-performance windows	Heating-cost savings in 3000 HDD climate may justify triple glazing, two low-e coatings and argon fill. Further measures may be justified through savings in mechanical equipment and radiators due to smaller heating and cooling loads	3.3.20
High-performance windows + radiant slab cooling	Overall cost, Vancouver office buildings: \$550/m^2, versus \$620/m^2 for conventional façade and HVAC system (while reducing energy use by 45%)	3.3.20
Double-skin façades	120–200% the cost of a normal façade for builders experienced with double-skin façades; downsizing of heating and cooling equipment can offset much of the incremental cost; elimination of vertical ducts with the gap serving as a supply/exhaust vent can result in no net cost. Costs are highly site-specific	3.4
Air leakage of 1.5 ACH at 50Pa instead of 3–4 in houses	No additional cost for experienced builders in Canada.	3.7.1
Lifecycle costs of higher levels of insulation	The minimum in lifecycle costs is quite broad, with lifecycle cost at maximum implemented levels of insulation less than lifecycle cost at levels that are prescribed by building codes in many jurisdictions, even at present energy costs and without consideration of externalities	3.8
Chapter 4, Heating Systems		
Transpired solar collectors	Economics is highly favourable in large-scale applications (at least), with a simple payback of the order of 3–4 years in Toronto (4000 HDD) for natural gas at \$12/GJ. Future galvanized steel and plastic collectors might be significantly less costly	4.1.9
Furnaces	Condensing units more expensive than non-condensing furnaces (about 30% greater installed cost) due to need for corrosion-resistant heat exchanger, and modulating units more expensive still due to additional valves and controls. Larger premium in retrofits if condensing furnace replaces non-condensing furnace due to need to block chimney	4.2.1 & 4.2.8
Wood-pellet boilers	Considerably more expensive than oil boilers, but less so at larger sizes	4.2.2
Heating-only absorption heat pump	\$2000 more than a 29kW_{th} residential furnace	4.2.4
Commercial condensing boilers	25–100% more expensive than non-condensing boilers in North America due to immature market, partially offset where possible by choosing a greater number of smaller units so that there is less backup capacity and hence less total capacity. Typical non-condensing cost: \$30–75/kW_{th}	4.3.1

Equipment for building-scale cogeneration	Reciprocating engines, \$900–1400/kW_e installed; Microturbines: \$1800–2600/kW_e installed; Fuel cells, \$3200–5500/kW_e	4.6.1
Chapter 5, Heat Pumps		
Ground source heat pumps	Will often have greater upfront cost but with a favourable payback in many cases. Upfront costs can be comparable to first cost of conventional systems in some cases. Ground loop is the most expensive part, but its cost can be reduced if the ground loop is integrated into building piles (if present) or into excavation and replacement of excavated material next to the building (if needed for structural reasons), and/or if the loop can be downsized in various ways	5.3.6 & 5.9
Hydronically coupled heat pumps	Factor-of-ten downsizing in size of heat exchangers through microchannel heat exchangers should lead to a significant reduction in the cost of heat pumps	5.7
Heat pump water heater	\$1400 compared to \$400–500 for comparable electric resistance heaters, but cost premium could drop substantially.	5.11
Solar-assisted heat pump for domestic hot water	Improved performance generally not likely to justify increased cost and complexity compared with solar DHW heater alone. 2-year payback in Singapore compared to electric resistance water heater and 13 cents/kWh electricity	5.13.2
Chapter 6, Cooling Loads and Cooling Devices		
Low-cost measures to reduce cooling load (building shape and orientation; albedo; added insulation; external shading; windows with low SHGC; thermal mass)	Cost largely or entirely offset by downsizing or elimination of mechanical cooling equipment	6.2
Features (atria, solar chimneys, airflow windows and double façades, trickle ventilators, wind cowls) to facilitate passive, hybrid, and night-time ventilation	Cost partly offset by downsizing or elimination of mechanical cooling equipment	6.3
Evaporative coolers	\$200/kW_c in the US market, compared with \$200–450/kW_c for ductless split air conditioners, and likely to fall at least 30% in cost	6.3.7
Vapour compression chillers	Terminal air conditioners, \$400–700/kW_c at 4.4–1.7kW_c capacity; multizone rooftop air conditioners, \$300–1500/kW_c at 400–600kW_c capacity; air-cooled reciprocating chillers, \$150–330/kW_c at 1500–50/kW_c capacity; centrifugal chillers, \$80–130/kW_c at 7000–300kW_c capacity	6.5.4
Absorption chiller	\$85–350/kW_c, competitive in cost with centrifugal chillers of 2.5MW_c capacity and larger. Greater cost per unit of cooling capacity the lower the regeneration temperature	6.6.1
Adsorption chiller	\$550–2200/kW_c for capacities of 50–430kW_c	6.6.2
Solid desiccant/ evaporative cooling	\$400–700/kW_c for capacities of 20–350kW_c	6.6.4
Liquid desiccant dehumidification	More expensive than solid desiccant cooling, but may drop to \$230–260/kW_c	6.6.5
Correct sizing of cooling equipment	Potentially significant reduction in capital cost and modest energy savings	6.8
Ice thermal storage	No net increase in capital cost possible	6.9.4
Eutectic salt thermal storage	No net increase in capital cost possible	6.9.4

Chapter 7, HVAC Systems		
High-performance filters	1-year simple payback on incremental cost	7.1.2
Correct pump sizing	Potentially modest reduction in capital cost and significant savings in pump energy use	7.1.3
Personal environmental modules	Reduced overall HVAC cost due to downsizing of equipment and warmer permitted supply temperature	7.2.5
Premium furnace blower (with ECPM motor)	Four times the cost of standard motor, but 2–3 year simple payback at US electricity costs; should drop to 2–3 times cost of standard motor with volume	7.3.2
Chilled ceiling cooling combined with high-performance building envelope	Same or smaller cost than conventional VAV cooling system and envelope	7.4.4
Displacement ventilation	Same or smaller cost than conventional VAV cooling and ventilation system. Reduced churn costs	7.4.5
Demand-controlled ventilation with CO_2 sensors	2–3 year simple payback through energy cost savings	7.4.6
Task/ambient conditioning	Reduced capital cost due to equipment downsizing	7.4.7
Sensible heat exchanger between exhaust and supply air	Reduce peak cooling and heating loads, allowing equipment downsizing that offsets part or all of the cost of the heat exchanger	7.4.9
Cogeneration/desiccant dehumidification/radiant-slab cooling	4-year simple payback compared to conventional all-air HVAC system in one study	7.4.14
Duct sealing	10-year simple payback through energy cost savings, shorter if cooling and air-handling equipment can be downsized	7.4.15
Occupant responsive fume-hood ventilation with heat recovery	Less than 2-year simple payback	7.4.17
Commissioning	1–3% of HVAC cost	7.5
Chapter 9, Lighting		
Daylighting and shading control systems	Expensive, but costs reduced through use of a single transformer for several DC-motorized shades and sequential rather than simultaneous operation Dimmable ballasts currently \$60–120 each but could fall to \$20–30 each. Simplified systems can reduce cost significantly with minimal impact on energy savings. Part of cost will be offset by downsizing of cooling equipment and electrical system	9.3.2
Air-tight, CFL downlights	Prototype concepts reduce costs significantly	9.4
Chapter 10, Appliances, Consumer Electronics, and Office Equipment		
Horizontal-axis washing machines	Substantially more expensive than vertical-axis machines but generally lower-cost over their lifetime	10.1.2
Consumer electronic products with low standby power draw	Generally no more expensive than standard products	10.2
Chapter 11, Active Collection and Transformation of Solar and Wind Energy		
PV electricity	24–33 cents/kWh (high solar irradiance, 4% interest) to 30–45 cents/kWh (mid solar irradiance, 4% interest) at present. Cost could drop in in half, which would make it competitive with costs of grid electricity at the time that PV power is most available (i.e. at times of peak load)	11.2.5
Solar thermal energy, mid-European conditions	9–23 eurocents/kWh for DHW 40–50 eurocents/kWh for combisystems 10–13 eurocents/kWh for district heat without seasonal storage, 16–42 eurocents/kWh with storage	11.4.5

Flat-plate solar collectors	200–500€/m² in Europe; 30–35€/m² in China	11.5.1
Solar thermal absorption chiller cooling	\$1400/kW_c for a complete system with compound parabolic collectors and double-effect absorption chiller in California; 3000€/kW_c for a system in Greece; economics much more favourable in China	11.5.1
Solar thermal desiccant dehumidification and cooling	High cost if sized to meet 70–90% of cooling load in Europe (required in order to reduce primary energy use for cooling by 50%), less costly if collector cost is assigned in whole or in part to winter heating	11.5.5
Energy self-sufficient house with PV/T in The Netherlands	35 eurocents/kWh for heat, including cost of radiant floor distribution system	11.6
Chapter 12, Embodied Energy		
Appropriate traditional building materials	Up to 45% less expensive than modern materials in India (with 60% less embodied CO_2 emission)	12.4
Chapter 13, Advanced New Buildings		
CEPHEUS (Cost-Effective Passive Houses as European Standards) houses	Passive Houses have 10–20 times less heating energy than conventional houses; 'cost-effective' is defined as houses where the energy-cost savings pay back the incremental investment in 30 years or less. Cost of saved energy is 6.1 eurocents/kWh averaged over 13 cases (range: 1.1–11 eurocents/kWh)	13.2.1
Measures to reduce energy use by 56–77% in new US houses	Energy cost savings largely cancel incremental financing costs in simulation study	13.2.1
Building America programme, residential housing	50% savings in heating energy, 30% in cooling energy at negligible upfront cost	13.2.2
C-2000 (commercial building) projects in Canada	35–50% savings over ASHRAE 90.1-1989 at little or no additional cost	13.3
6 LEED buildings in US	Average cost premium <2% while saving an average of 50% in energy use	13.3.4
Solar Bau (commercial building) programme in Germany	33–85% savings at a cost comparable to the difference in cost of alternative interior finishings	13.3.4
Integrated design of Chicago office	1.6-year payback for 27% savings, 4.6-year payback for 36% savings, 2-year payback for 44% savings	13.3.4
16-storey building, Oregon Health & Science University	60% savings over ASHRAE 90.1-1999 with reduced first cost	13.3.4
Chapter 14, Retrofits of Existing Buildings		
ACT² project, California	45–50% savings with modest payback	14.2
Proposed retrofits of ten European offices	46–80% estimated savings with 10–15 year simple payback	14.2
Chapter 15, Community-Integrated Energy Systems		
Natural gas power plants for cogeneration	\$700–1900/kW for simple cycle cogeneration; \$400–860/kW for combined cycle cogeneration	15.2.6
District heating and cooling systems	Economies of scale for heating or cooling units, and reduced total capacity due to peak loads in individual buildings not coinciding, can more than offset the cost of pipes in high-density developments, thereby reducing total cost	15.3.10
Eight solar-assisted district heating systems completed in Germany (30–62% solar fraction)	16–42 eurocents/kWh	15.5.3
Large-scale seasonally stored solar heat in Sweden	11 eurocents/kWh	15.5.3
Medium-scale seasonally stored solar heat and district heating in Alberta, Canada	15 cents/kWh for the initial project	15.5.3

16.4 Policy directions

A number of conclusions clearly emerge from the summary tables presented here and from the broader discussion throughout this book:

1. Most of the technologies needed to achieve levels of energy use in buildings consistent with sustainability and with stabilization of atmospheric CO_2 at 450ppmv already exist and are well understood, at least in some jurisdictions.
2. Although there is a role for technology transfer between so-called 'developed' and 'developing' countries (i.e. between OECD and non-OECD countries), there is at least as great a need for technology transfer *between* various OECD countries as well as *within* individual OECD countries (i.e. from the few architectural and engineering design firms that are on the cutting edge, to the rest).
3. A corollary of (2) is that there is no need to wait for technological development to progress before beginning ambitious programmes targeting deep reductions in energy use and CO_2 emissions in the buildings sector.
4. Although significant reductions (factors of two to ten) in energy use can be achieved in retrofitting existing buildings, it is generally not possible to achieve as low an absolute energy intensity as can be achieved in new buildings, and such reductions as can be achieved entail greater cost than if buildings are designed from the beginning to require minimal use of energy.
5. A corollary of (4) is that, by delaying programmes to dramatically reduce the energy intensity of new buildings, or the energy intensity of old buildings when they require major renovations, significant windows of opportunity will be lost (irreversibly in the case of new buildings).

The primary barriers to achieving deep (factors of 3–5) reductions in CO_2 emissions in new buildings are not technological (because technologies and, more so, system designs, already exist that can provide deep reductions) nor even economic (because fully integrated designs entail very little and often no additional upfront cost compared to current conventional practice). Rather, the barriers are behavioural in nature: they involve the fragmented nature of the design process and resulting lack of optimization, lack of awareness, time constraints during the design process, and an over-reliance on established ways of doing things. There is a widespread if not universal perception that low-energy buildings must, *of necessity*, entail greater capital costs. This leads to a lack of desire on the part of the client to have a low-energy building, and without a committed client, architects and engineers will usually not undertake the additional design effort required to produce low-energy buildings.

Lack of awareness of energy savings opportunities among practising architects, engineers, lighting specialists and interior designers is a major impediment to the construction of low-energy buildings. This in part is a reflection of inadequate training at universities and technical schools, where the curricula often reflect the fragmentation seen in the building-design profession. There is a significant need, in many countries, to create comprehensive, integrated programmes at universities for training future architects and engineers in the design of low-energy buildings, with parallel programmes at technical schools for training technical specialists. The value of such programmes would be significantly enhanced if they have an outreach component to upgrade the skills and knowledge of practising architects and engineers and to assist in the use of computer simulation tools as part of the integrated design process

The purpose of this book has been to assess how and to what extent energy intensity in new and existing buildings can be reduced. It is beyond the scope of this book to deal extensively with the policies needed to achieve these reductions. Nevertheless, it is appropriate to outline some of the key actions required:

1 Upgrading the teaching of building sciences at universities (in architecture and engineering departments), community colleges and vocational schools with, in particular, the creation of comprehensive, integrated programmes that combine all of the elements needed to create truly sustainable buildings.
2 Developing university-based outreach programmes to improve the design process among practising design firms (architectural and engineering)
3 Undertaking 'market transformation' programmes so that high-performance buildings, designed using the integrated design process, are increasingly what the market expects. This could entail financial support for high profile projects that demonstrate large savings at little to no incremental cost (many examples of which already exist and have been documented in this book), incentives to support the additional cost of design using the integrated design process, and training in the integrated design process.
4 Upgrading building codes, providing training in meeting upgraded building codes, and providing enhanced inspection ability to increase the degree of compliance with the upgraded building codes.
5 Providing financial support for continued improvement and reduction in the cost of a wide array of promising advanced technologies that further increase the potential for reducing the energy intensity of buildings, particularly of the large stock of existing buildings.

16.5 Is sustainability feasible?

A sustainability energy system is a system that can continue indefinitely, which implies that it is based entirely on renewable energy sources. Although the energy flow from the sun that is intercepted by the Earth is enormous, solar energy is diffuse, intermittent and not always available where or when it is needed. This places limits on the rate at which renewable energy sources can be supplied to major population centres. Current levels of per capita energy consumption in OECD countries are clearly not sustainable. Buildings themselves can serve as collectors and transformers of solar energy, but for this intercepted energy to meet a large fraction of the building energy needs (with the balance eventually provided by renewably based grid energy), total energy demand must be kept small.

Sustainable new buildings were defined in Chapter 1 (Section 1.4.3) as buildings that, among other things, achieve a factor of four to five reduction in energy intensity (energy use per unit floor area) compared to recent new buildings in OECD countries. This book has presented several examples of buildings that have achieved energy-intensity reductions of this magnitude (see Table 13.15), although factors of two to three reduction are more common. To achieve a factor of four to five reduction is pushing the energy-efficiency measures considered here to the limit. There is no room for half-measures if true sustainability is to be achieved. The criterion presented here for sustainability in new buildings assumes that the energy intensity of that portion of the existing building stock that is not eventually demolished can be reduced by about 40–60 per cent, which is readily achievable through extensive and comprehensive retrofits (as discussed in Chapter 14). If larger savings in the existing stock can be achieved through retrofits, then there will be less pressure to reduce the energy intensity of new buildings.

Thus, we may tentatively conclude that sustainability in the buildings sector is achievable, but it requires making use of every available opportunity to reduce the energy demands of buildings, and it requires that we begin immediately so as to reduce the buildup of inefficient building stock that serves as a future liability. This book is directed to those who are in a position to do that and, it is hoped, will contribute to this urgent process. The well-being of future generations, and the preservation of at least some portion of our priceless ecological and evolutionary heritage, is dependent on it.