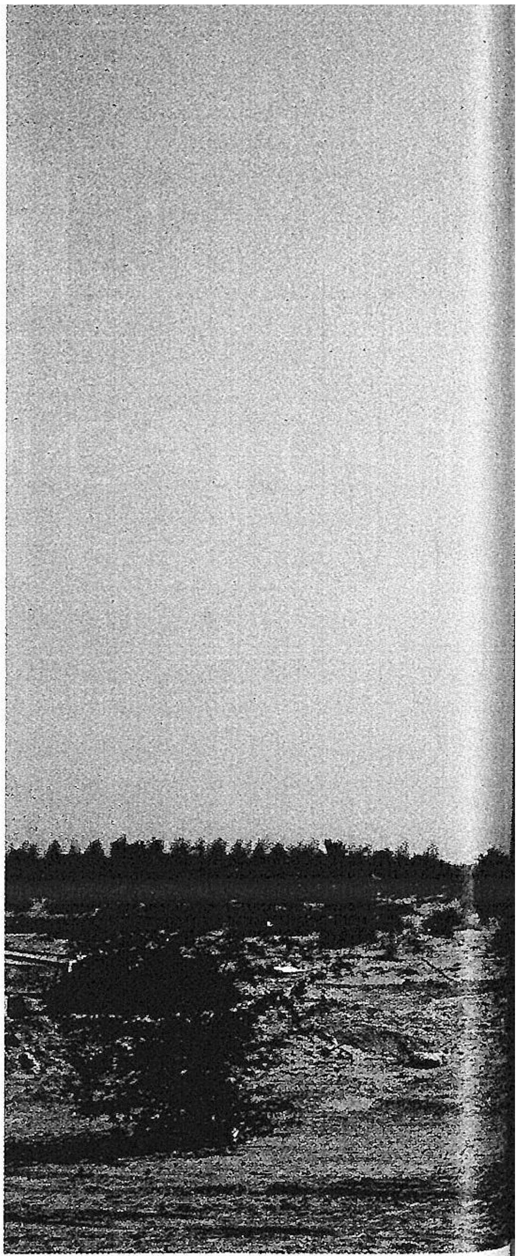
A Zero-Emissions City in the Desert

OIL-RICH ABU DHABI IS BUILDING A GREEN METROPOLIS. SHOULD THE REST OF THE WORLD CARE?

By KEVIN BULLIS



The first hints of the project are visible. A white wall stretches through the desert, like a chalk line on a dusty playing field. A bus with darkened windows stirs a low cloud, ferrying workers past a cluster of steel cranes, two portable drilling rigs, and a stand of concrete columns sprouting rust-colored rebar. A tall wire fence guards rows of solar panels mounted on concrete pads.

The construction is the start of a vast experiment, an attempt to create the world's first car-free, zero-carbon-dioxide-emissions, zero-waste city. Due to be completed in 2016, the city is the centerpiece of the Masdar Initiative, a $15 billion investment by the government of Abu Dhabi, which is part of the United Arab Emirates. The new development, being built on the outskirts of Abu Dhabi city, will run almost entirely on energy from the sun and will use just 20 percent as much power as a conventional city of similar size. Garbage will be sorted and recycled or used for compost; sewage will be processed into fuel. Concrete columns will lift the city seven meters off the ground, creating space underneath for a network of automated electric transports that will replace cars. Planners predict that the development will attract 1,500 clean-tech businesses, ranging from large international corporations to startups, and—eventually—some 50,000 residents.

The city will be an oasis of renewable energy in a country of five million, made rich by oil, that consumes the most natural resources per capita in the world. Seen one way, it's just the latest ostentatious project in a country that's been defined by them. Indeed, the UAE is already home to the world's tallest building and an enormous indoor ski facility that features a 200-meter-long black-diamond slope. Real-estate developers have dredged coral and sand from the sea floor, piling it up in the Persian Gulf to create islands in the shape of palm trees and a map of the world.

Yet many experts are optimistic that the city can become a test bed for new approaches to the engineering and architectural problems involved in creating environmentally sustainable cities. Although architects have already designed and builders constructed many small zero-emissions residences and commercial

DESERT CITY The Masdar City development, near Abu Dhabi, was in the first stages of construction last October. In the distance, cranes erect the first building, a research institute.

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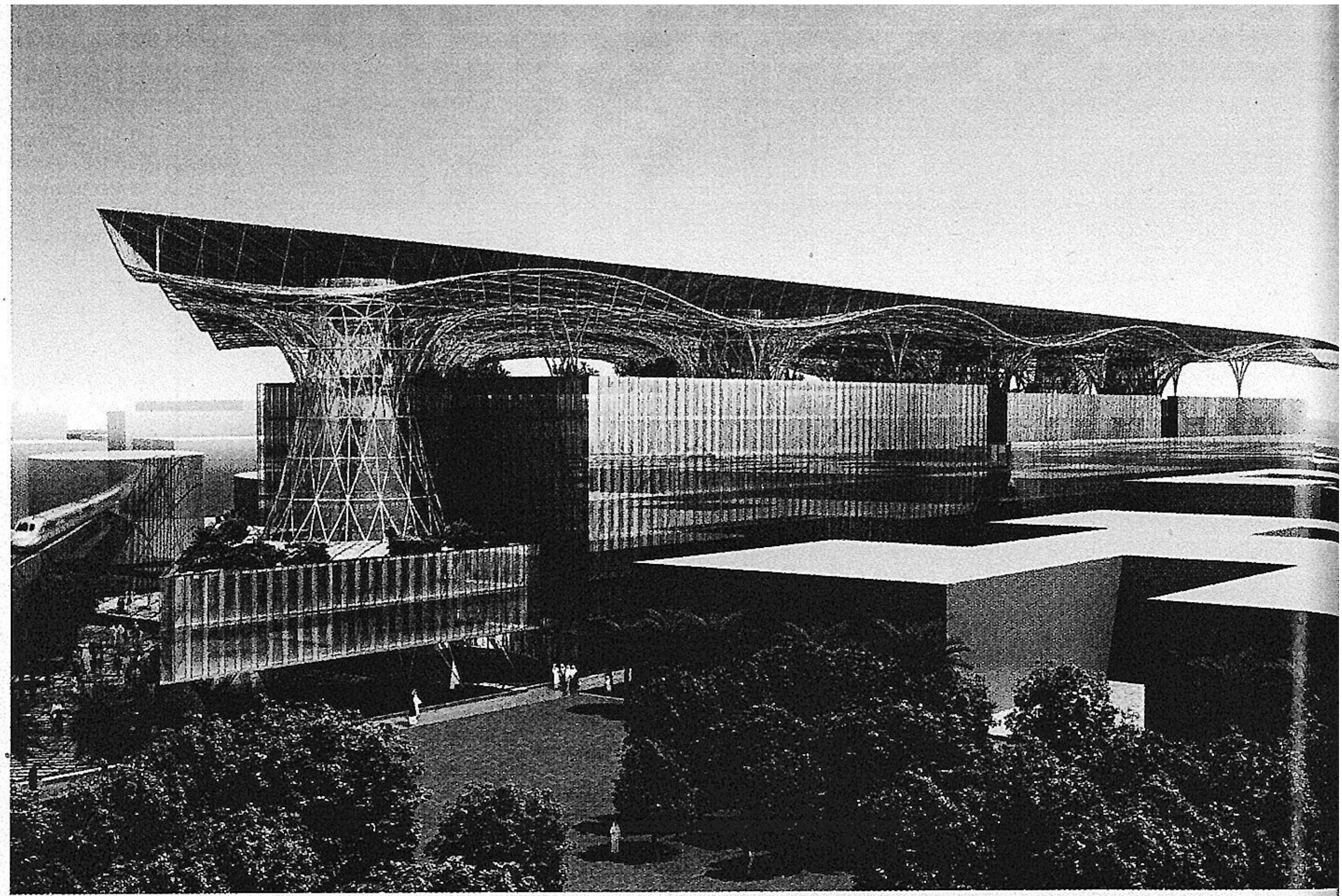
buildings, projects involving large, multi-use commercial buildings have fallen short of expectations, using too much energy or failing to generate enough. Part of the problem is the growing complexity that comes with scale, says J. Michael McQuade, senior vice president of science and technology at United Technologies in Hartford, CT; today's design software hasn't been able to handle it. But Masdar City, itself developed with the help of extensive modeling, will be wired from the beginning to collect data that could prove valuable for developing better models. That information could make future zero-emissions cities cheaper and easier to build.

And the development is meant to make money, not just introduce new technology. "We want Masdar City to be profitable, not just a sunk cost," said Khaled Awad, the project's director of property development, at a huge real-estate exhibition in Dubai last fall. "If it is not profitable as a real-estate development, it is not sustainable." Yet if it is, it may be replicable.

"If environmental engineers, by gaining experience from building this wild city, become much more productive at building the next city, this starts to move from being science fiction to something Houston would adopt," says Matthew Kahn, a professor



ENERGY SURPLUS Masdar headquarters, shown above in an architectural rendering, is designed to generate more renewable electricity than it consumes; it would be the first large-scale, multi-use building to do so. Opposite: The building's structural cones, which support a roof laden with solar panels, will also provide light and ventilation. The pond helps cool the air.

of economics at the University of California, Los Angeles. Gil Friend, CEO of Natural Logic, a sustainable-design company based in Berkeley, CA, agrees. "I see Masdar on the one hand as a playground for the rich," he says, "and on the other hand as an R&D opportunity to deploy and test out technology that, if things go well, will show up in other cities."

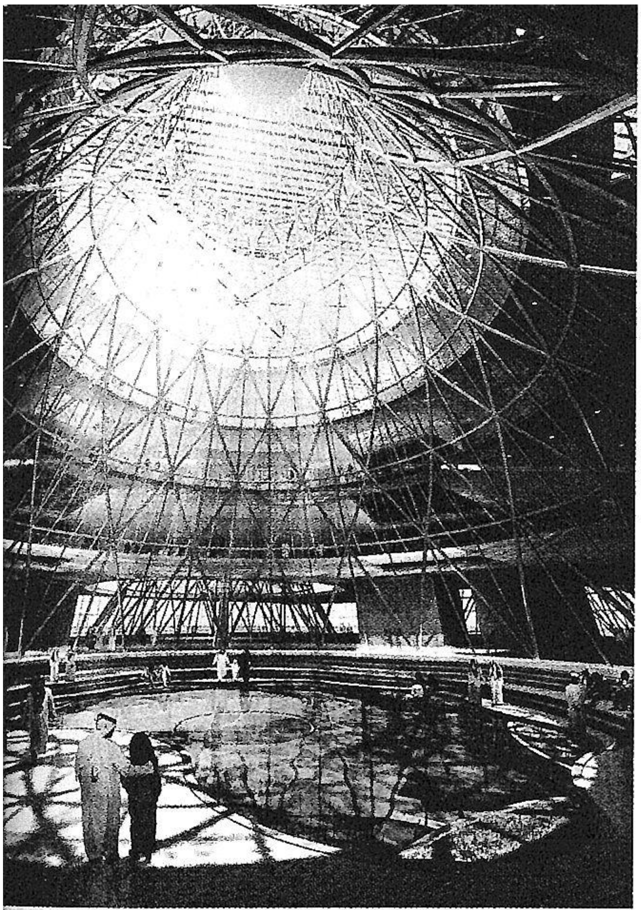
Of course, much of what's learned from Masdar won't apply outside the incredibly hot and sunny coast of the Persian Gulf. A site in Germany, which wouldn't get as much sunlight, couldn't rely as heavily on solar energy. A site in San Francisco might not need air conditioning, making information about advanced cooling systems less relevant. But if the project reaches its environmental goals, it will at the very least show that such cities can be built. "People say, 'Gee, that would be great. That would be a good idea, but obviously it's not possible,'" Friend says. "Once you can point at something, it takes away a lot of those arguments."

BREAKING GROUND

The Masdar Initiative is part of an ambitious plan to transform a resource-based economy—the third-largest exporter of oil in the world—into one based on knowledge and expertise. The name Masdar comes from the Arabic word for "source," and the plan is to make Abu Dhabi the Silicon Valley of alternative energy: a source of talent, patents, and startups in the very industry that could one day challenge the supremacy of oil. It's a daunting challenge to say the least, especially for a region that, according to Awad, "hasn't been known for innovation for a thousand years."

The city was conceived as a tax-free zone meant to attract clean-technology companies, largely from other countries. (The first tenant, General Electric, plans to build a 4,000-square-meter facility.) The Masdar Institute, the first part of the city to be built, is meant to be what Stanford University is to Silicon Valley. Developed in collaboration with MIT, which organized the curriculum and is helping to select and train the faculty, the institute will be a graduate research school, offering master's degrees and, eventually, PhDs. Its first class of 100 students will start courses this fall. And if graduates develop promising ideas and start companies, they can look to the Masdar Initiative for capital. Of the $15 billion the government has set aside so far for the initiative, only about $4 billion is designated as seed money for building the city's infrastructure. (The city is expected to cost a total of $22 billion, the rest to come from outside investors.) The remaining $11 billion is earmarked for a range of investments; projects so far include a solar-cell factory in Germany, an offshore wind farm in the United Kingdom, and efforts to reduce carbon emissions in Nigeria.

Still, the city is the most visible part of the initiative. It is by far the largest zero-emissions and zero-waste project in the world, according to several experts. (A larger "eco-city" development near Shanghai doesn't aspire to zero emissions.) Efforts elsewhere have



so far been limited to small to moderate-sized buildings and small communities, like a series of efficient row houses for 250 people in Wallington, South London. One of the most ambitious zero-emissions buildings to date, the Lewis Center at Oberlin College in Ohio, has 1,263 square meters of floor space. Masdar City will cover six square kilometers. Its headquarters alone, which will include offices as well as retail and cultural space, will occupy an 89,500-square-meter structure.

A detailed master plan for the city is complete, as are plans for the first buildings: the Masdar Institute and the headquarters. The city—which will include apartments and laboratories, but also factories, movie theaters, cafés, schools, fire stations, and so on—is intended to generate as much electricity as it uses. Its water will be recycled to save the energy costs of desalination. Vacuum tubes under the city will transport garbage to a central location, where it will be sorted, and as much as possible will be recycled. Trash that can't be recycled will be converted to energy through a gasification process and the leftovers incorporated into building materials. Sewage will be treated and some of it processed into a dry renewable fuel for generating electricity. The transportation system will include a light-rail line linking the development to downtown Abu Dhabi and the airport, as well as a personal rapid-transit (PRT) system with stations throughout the city. The PRT, a system of automated electric vehicles, will connect people to the rail line or deliver them to parking garages outside the city.

As is typical for zero-emissions projects to date, the city will need to rely in part on fossil fuels—both during construction and for power at night, when its solar panels won't be producing any electricity. The goal is actually best described as zero *net* carbon dioxide emissions: to reach the zero-emissions target, the developers will turn to a system of carbon credits. As the city is being built, a 10-megawatt array of solar panels will deliver power to nearby Abu Dhabi city, reducing demand for electricity from local natural-gas-fired power plants during the day. The carbon emissions saved will offset the emissions produced at night, when Masdar draws power from those same natural-gas plants. This solar array, and additional panels that will be installed as construction continues and electricity demand grows, will also offset the carbon emissions from construction equipment, from the processes used to make building materials such as concrete, and even from consultants' flights into Abu Dhabi from cities around the world.

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So far, the developers have been accounting for "just about everything," says Pooran Desai, cofounder of BioRegional, a British company that helped develop the zero-emissions project in London and has consulted for Masdar. "I don't know of any other project that has been as thorough in terms of its carbon monitoring," says Desai. "They're hunting down every molecule of carbon dioxide."

THE MASTER PLAN

Dubai is a sprawling, car-dominated city about an hour's drive from Abu Dhabi city. Skyscrapers stretch along a 12-lane highway, Sheikh Zayed Road. Sunlight heats the unshaded areas to 46 °C in the summer. But there are a few places in Dubai where a person can walk outdoors in the middle of the day without risking heatstroke, and all are artifacts of the past. There are the covered souks, shaded marketplaces. And there is a historic district called the Bastakiya, which preserves some of the architecture that protected locals from the heat and humidity before the arrival of air conditioning. The houses and shops have thick walls made of dried coral and gypsum that absorb heat during the day, releasing it slowly at night. Because the buildings are packed closely together, they shade both each other and the narrow passages between them. The passages funnel breezes, cooling the buildings further.

When Gerard Evenden, a senior partner at the British firm Foster and Partners, began to make the master plan for Masdar City, he

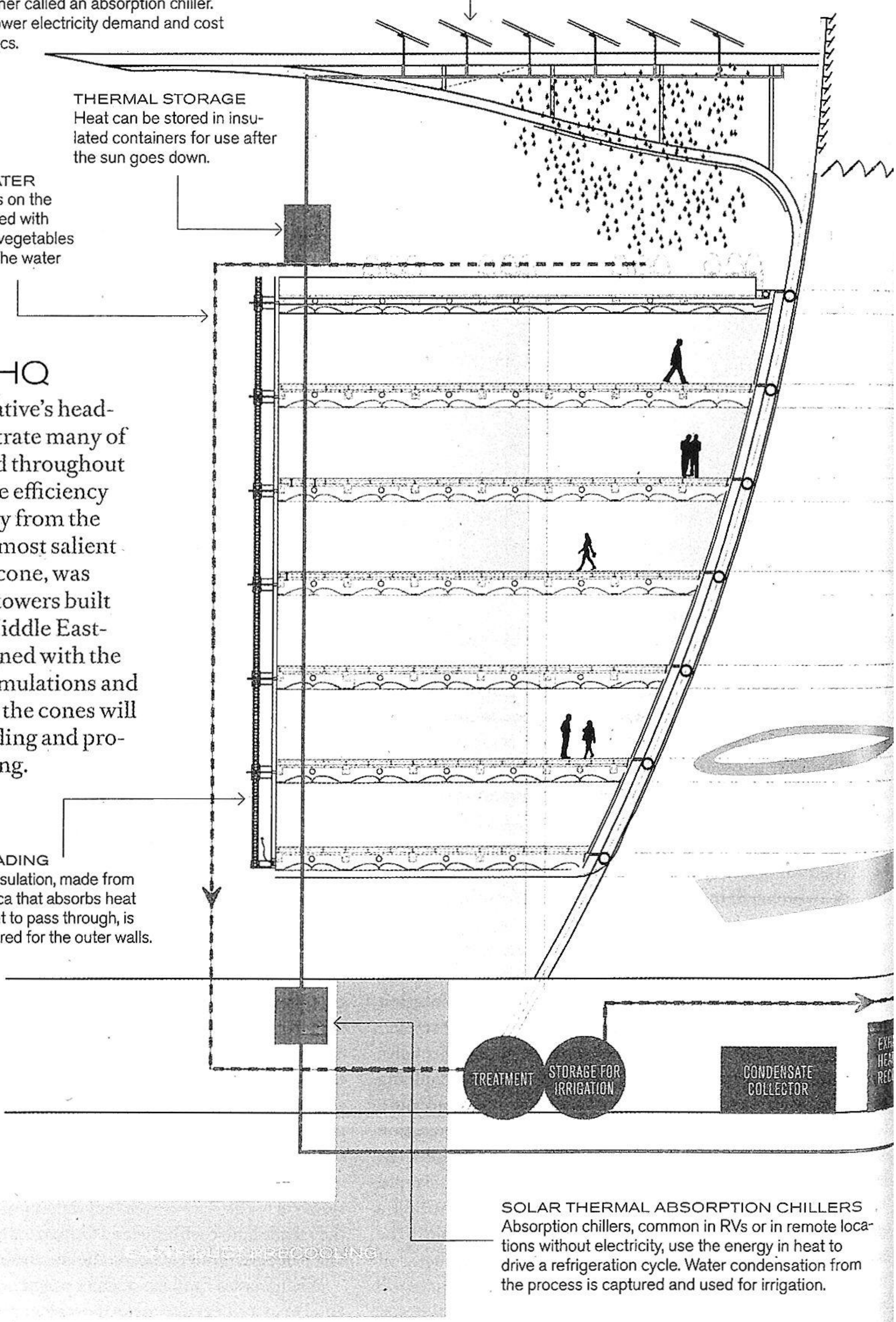
SOLAR THERMAL COLLECTORS
Concentrated heat from the sun heats water to run a type of air conditioner called an absorption chiller. Thermal collectors lower electricity demand and cost less than photovoltaics.

THERMAL STORAGE
Heat can be stored in insulated containers for use after the sun goes down.

IRRIGATION WATER
What little rain falls on the city will be combined with irrigation to water vegetables and other plants. The water will be recycled.

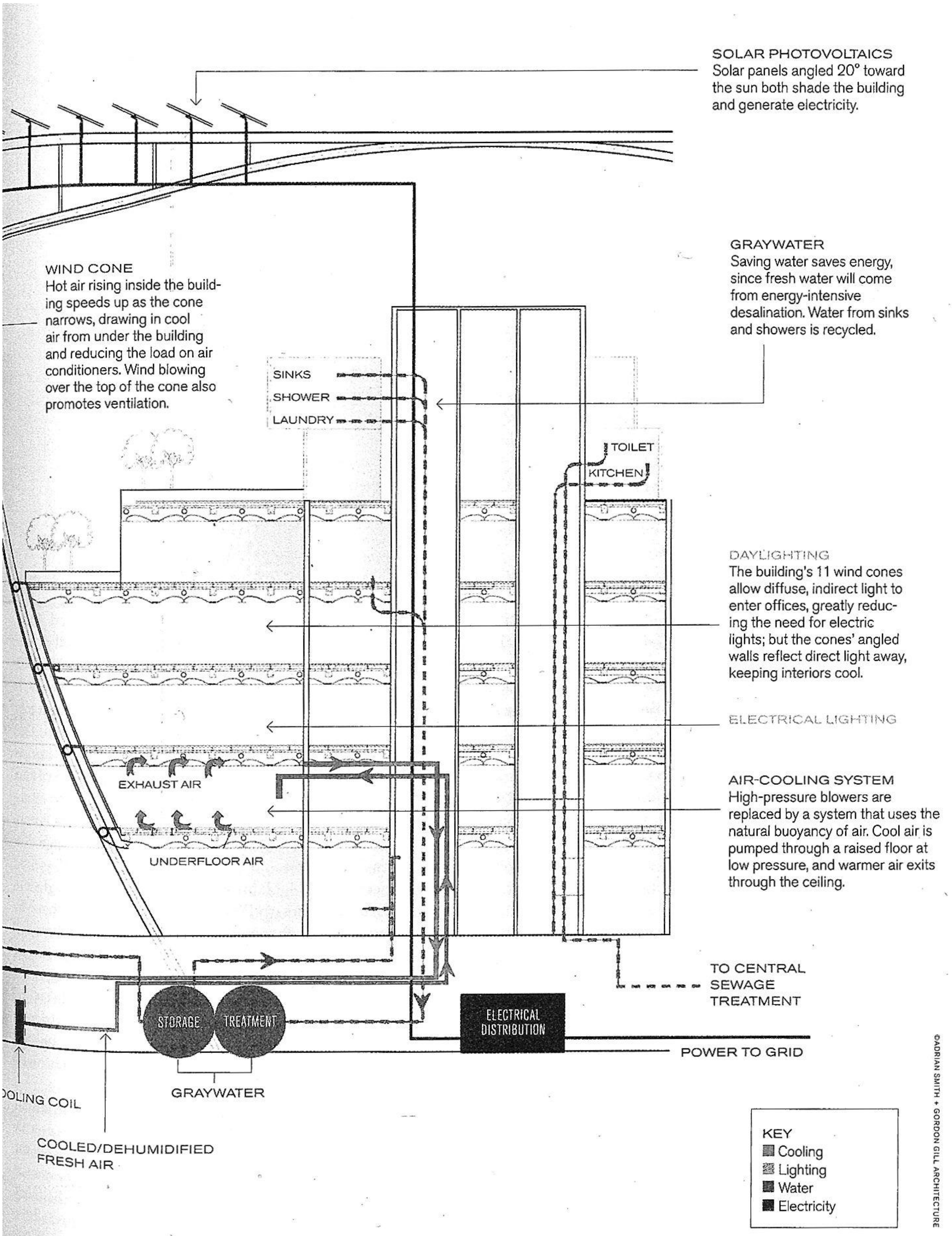
MASDAR HQ

The Masdar Initiative's headquarters will illustrate many of the strategies used throughout the city to increase efficiency and harvest energy from the sun. The design's most salient feature, the wind cone, was inspired by wind towers built into traditional Middle Eastern houses. Designed with the help of detailed simulations and wind tunnel tests, the cones will help cool the building and provide natural lighting.



SOLAR SHADING
Translucent insulation, made from nanoscale silica that absorbs heat but allows light to pass through, is being considered for the outer walls.

SOLAR THERMAL ABSORPTION CHILLERS
Absorption chillers, common in RVs or in remote locations without electricity, use the energy in heat to drive a refrigeration cycle. Water condensation from the process is captured and used for irrigation.


SOLAR PHOTOVOLTAICS
Solar panels angled 20° toward the sun both shade the building and generate electricity.
WIND CONE
Hot air rising inside the building speeds up as the cone narrows, drawing in cool air from under the building and reducing the load on air conditioners. Wind blowing over the top of the cone also promotes ventilation.
GRAYWATER
Saving water saves energy, since fresh water will come from energy-intensive desalination. Water from sinks and showers is recycled.
SINKS
SHOWER
LAUNDRY
TOILET
KITCHEN
DAYLIGHTING
The building's 11 wind cones allow diffuse, indirect light to enter offices, greatly reducing the need for electric lights; but the cones' angled walls reflect direct light away, keeping interiors cool.
ELECTRICAL LIGHTING
EXHAUST AIR
UNDERFLOOR AIR
AIR-COOLING SYSTEM
High-pressure blowers are replaced by a system that uses the natural buoyancy of air. Cool air is pumped through a raised floor at low pressure, and warmer air exits through the ceiling.
TO CENTRAL SEWAGE TREATMENT
STORAGE
TREATMENT
ELECTRICAL DISTRIBUTION
POWER TO GRID
OOLING COIL
GRAYWATER
COOLED/DEHUMIDIFIED FRESH AIR
KEY
Cooling
Lighting
Water
Electricity

looked to such traditional designs for ways to save energy. Since the city will depend almost entirely on electricity from solar power, which is five times the price of electricity from the local grid, the city needs to be roughly five times as energy efficient as competing developments nearby.

One of the first things Evenden did was subtract cars: with the highways gone, the city's buildings could be separated by passages just 7 to 12 meters wide, close enough to shade each other yet far enough apart to let in indirect light. That's a cheap way to reduce the need for not only air conditioning but electric lighting, the largest drain on electricity in commercial buildings. Insulation is cheap, too: in the Masdar Institute, Evenden plans to use 30-centimeter-thick insulation to keep out the heat. He's also incorporating "skins" of copper foil that reflect light and conduct heat away from the buildings. The foil will be protected from the desert dust by a self-cleaning Teflon-like plastic. To reduce the need for energy-intensive desalination, Evenden's design will cut water consumption by 75 percent through recycling, low-flow fixtures, and waterless urinals.

A small fraction of the energy that's still needed to run the city will come from waste-based fuel and perhaps geothermal power. The rest will come from the sun—but not all of it through expensive photovoltaics, which convert sunlight into electricity. Much cheaper devices that concentrate heat from the sun will heat water and run a type of air conditioner called an absorption chiller. (This is the same kind of technology that is used now in propane-powered refrigerators.)

In theory, it should all work. But in practice, even much less ambitious projects have failed. Oberlin College's Lewis Center features many of the same elements of energy-efficient design: thick insulation, natural ventilation with heat exchangers, plenty of windows to offset the need for electric lighting, and heat pumps rather than conventional furnaces. A 60-kilowatt array of solar panels on its roof was supposed to produce as much electricity over the course of a year as the building consumes. Yet the building initially used too much energy, and the solar panels were not adequate. To achieve zero net energy, the college had to install an extra solar array nearby, more than tripling the total power production. It added over a million dollars to an already expensive building, estimates John Scofield, a physics professor at Oberlin who has published a detailed analysis of the building's performance.

In general, architects find that predicting how energy-efficient systems will interact gets much harder as buildings get bigger. In buildings designed to take advantage of natural light, for example, designers can install sensors to automatically switch bulbs off when enough light comes in from outside. But lights turning on or off in one sensing zone may affect the sensors in another. In some buildings this has created a feedback loop that makes lights cycle on and off annoyingly.

Neighboring heating and cooling zones can also affect one another to create complex and unpredictable feedback loops, especially as the number of zones increases. United Technologies' J. Michael McQuade recalls what happened when his company designed what was supposed to be an intelligent heating, ventilation, and air-conditioning management system for a new building in Paris. The system was designed to coördinate 3,000 different zones. "When that building was first put together, it was a significant energy consumer, and it took a revamp of the integrated control systems to get it right," McQuade says.

If zero-emissions buildings are to be economical, Scofield says, the designs will have work from the start. "If you don't get it right," he says, pointing to the fiasco at Oberlin, "every correction you make is so much more costly than getting it right the first time."

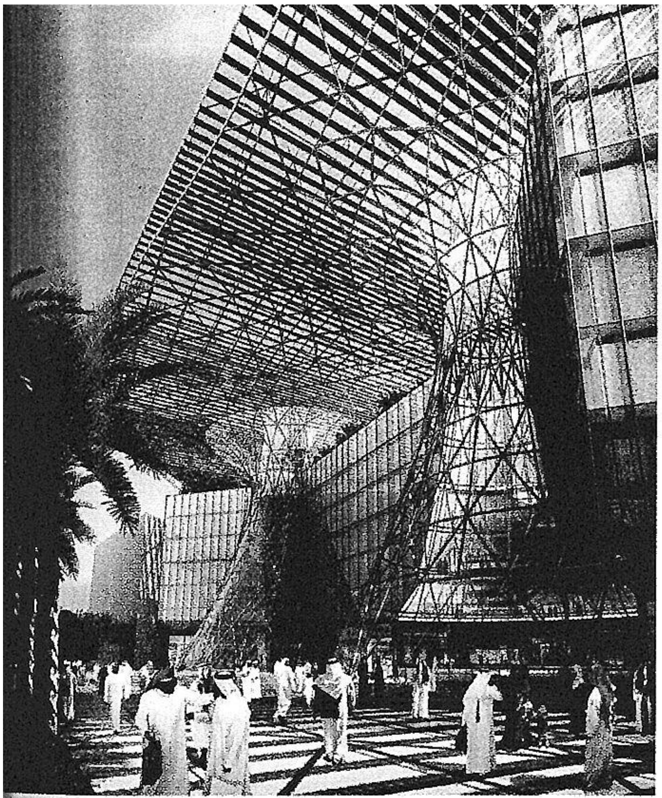
PERSONAL TRANSIT

Masdar City will be raised on concrete stilts to make room for a personal rapid-transit (PRT) system that will replace buses and trains with smaller vehicles designed for four people. Masdar's planners expect the system to use less energy than conventional mass transit, and they say it will be more convenient, too.

In a PRT system, several small vehicles, often called pods, are kept waiting at each station. An individual or a small group boards one and selects a destination; the pod proceeds automatically to the destination without stopping. In a typical design, each vehicle resembles a battery-powered golf cart, only it's completely enclosed and somewhat bigger—and it lacks a steering wheel. The vehicle follows a track, which is connected to stations by on-ramps and off-ramps, and a computer controls how the pods enter and exit the stations: the ramps allow individual pods to make stops while others continue along the main track at top speeds. Simulations suggest that the systems could run with as little as half a second between vehicles.

But although PRTs look promising, they haven't caught on. That's in part because an early PRT-like system built in the 1970s in Morgantown, WV, gave the idea a bad name, says Jerry Schneider, an emeritus professor of urban planning and civil engineering at the University of Washington in Seattle and a longtime advocate of PRTs. "People would get on the vehicles and they wouldn't stop," Schneider says of the system, a transit line with automated cars for about 20 people. Technology has improved since then, he says, but there hasn't been a significant real-world demonstration of the updated systems.

Two demonstration programs are on the way. The first, which will transport passengers to a new terminal at Heathrow International Airport near London, will open later this year. Tests of that system are already under way. And the first stage of the system at Masdar City, to be built by the Dutch firm 2GetThere, is scheduled to be in place for the opening of the Masdar Institute this fall.



SHADY LANE Solar panels on the roofs provide sun protection in public spaces between buildings.

THE TEST BED

Sameer Abu-Zaid isn't breaking a sweat. It's 39 °C with 74 percent humidity, but he says it's a nice day—much cooler than the summer in Abu Dhabi, when temperatures can reach 49 °C. Abu-Zaid, who's originally from Jordan and was most recently a manager at a semiconductor equipment manufacturer in Silicon Valley, will manage Masdar City's power and distribution infrastructure. "All of these modules have been tested at the factories," he says as he gives a tour of one of the first visible signs of the city, a test site where he's putting 41 arrays of solar panels from various manufacturers through their paces. "But they have been tested under standard test conditions: 1,000 watts per meter squared, 25 °C. Nice air-conditioned space. It is totally different here."

Dust from the desert quickly coats the panels, effectively dimming the light that reaches them. Abu-Zaid has learned that just four months of dust reduces the output of the solar arrays by more than 20 percent—information he'll use to decide how often to wash the panels, balancing power loss against water consumption.

Another problem is the heat. Solar panels' dark surfaces absorb sunlight, raising their temperature to as much as 80 °C. The heat affects some solar-cell technologies more than others. Some of the most efficient solar panels also produce less power when they get hot. Because of these trade-offs, it's not obvious which panels will work best at the Masdar site, Abu-Zaid says. At the test plot, sensors track how much various panels heat up, how effective different cooling strategies are, and how power output changes with temperature, among other factors.

Such data gathering will continue as the city grows. Its designers and engineers will measure both energy consumption and energy production. They will track water consumption down to the individual fixture. At Masdar headquarters, designers may use RFID tags in security badges to gather information on the way people use water and energy. Such measurements will allow designers and engineers to compare the real performance of the city with the performance predicted by laboratory tests and simulations.

REALITY CHECK

In the early 1960s, while the United States was rushing to put a man on the moon, electric fans and lights were still unheard-of in Abu Dhabi, according to Mohammed Al Fahim, a native of the emirate who has written a rare history of the place. That was not long after oil was discovered there, and well before the money started flowing. Al Fahim is from one of the wealthiest families in the area, yet both his sister and later his mother died because of a lack of basic health care. Now life expectancy in Abu Dhabi is virtually the same as in the United States. Before, the locals survived on water from brackish wells; now they drink fresh water from new desalination plants. The fragile and highly flammable palm-frond huts that housed most people have been replaced by gleaming glass-and-steel skyscrapers.

In many ways, the development of Abu Dhabi over the last few decades has reflected a frenetic effort to catch up with the developed world. Now, because of projects such as Masdar City, the emirate has a chance to race ahead. But in terms of urban development, it appears to be very much at a crossroads. In a few years, while the citizens of Masdar City will be pinching kilowatt-hours and using waterless urinals, go-carts will be screaming around a new track at a Ferrari theme park nearby, kids will be shrieking as they plummet down water slides at a new water park, and massive air conditioners will be roaring as they cool a new 700-store supermall. It's all part of a 2,500-hectare development that will dwarf the 640-hectare Masdar City.

The two developments are competing visions for the future of Abu Dhabi. If the Masdar project doesn't justify itself financially, it could indeed be just a green playground for the rich, an environmental theme park that is largely irrelevant for the development of sustainable technology on a broader scale. But if it is profitable, it could be a driving force for sustainable urban design. Then the oil-rich developers in the UAE and elsewhere might have a reason to build more green cities and skip constructing another ski slope in the desert. And developers worldwide will follow. TR

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