USER STORY

Greenhouse Designed with Simulink® Revolutionizes Agriculture in Arid Coastal Regions

The Light Works prototype seawater greenhouse in Tenerife, in the Canary Islands.

THE CHALLENGE

To enable the growing of temperate crops in arid coastal regions by developing a greenhouse that uses desalinated seawater to cool and humidify the environment

THE SOLUTION

Use MATLAB and Simulink to model the processes within the greenhouse, including ventilation, evaporation, and heat transfer

THE RESULTS

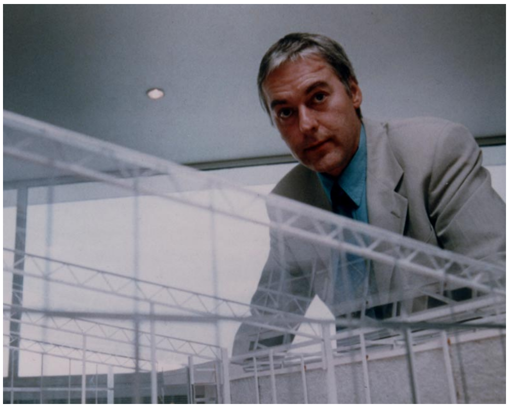
- Rapid, reliable simulation
- Energy-efficient new technology
- An award for architectural design

A unique type of greenhouse is helping people in some of the world's most arid regions to exploit what natural resources they have and improve their ability to feed themselves. The seawater greenhouse, which was designed and developed by Light Works, a lighting design company in London, England, converts seawater into fresh water and cools and humidifies the environment. Its cool, humid atmosphere has proved to be perfect for growing temperate crops, such as tomatoes, lettuces, and beans, in desert regions. Yields have been higher and growing times shorter than expected, and water use has been reduced by 80 percent.

MATLAB® and Simulink® were used to model and simulate a prototype of the system, which was subsequently built in Tenerife, in the Canary Islands. The Simulink model has become a powerful tool for refining the greenhouse processes and overall design to suit locations around the world.

THE CHALLENGE

Some of the world's driest desert regions are bordered by the sea, but the high cost of desalination has prevented the use of this valuable source of water. Light Works owner and director, Charlie Paton, and his colleague, Philip Davies, set out to create a system that would use seawater to grow much-needed crops at a reasonable cost.



Charlie Paton with a scale model of his seawater greenhouse.

A Simple Idea

Paton's concept—a building that exploits natural air conditioning and sunlight to convert seawater into fresh water—was a simple one. The greenhouse is a steel structure, covered in either fiberglass or plastic. The side walls are made of corrugated cardboard filters, over which seawater passes.

As hot air is pumped into the greenhouse, the seawater evaporates, depositing its salts on the cardboard. These salts strengthen the cardboard, enabling it to last indefinitely. The roof is double-skinned. Air in the cavity between the two skins is heated by infrared and ultraviolet light, helping to drive the evaporation process and reduce the temperature.

Air from the greenhouse passes through a condenser, which is cooled by seawater. Pure, distilled water is condensed out and used to water the crops in the greenhouse. Any surplus water can be stored and used elsewhere.

Complex Physical Processes

The idea was relatively simple. Getting it to work in practice, however, involved "several complex issues," says Paton. To address these issues before building the prototype he decided to create a thermodynamic model of the physical processes involved.

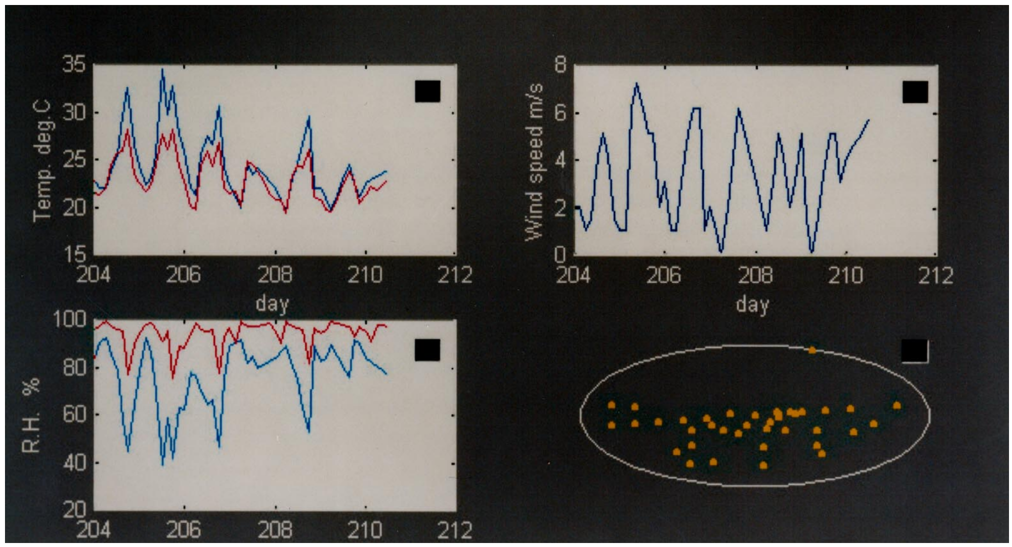
Modeling the workings of a conventional greenhouse would have been straightforward enough. But to model what was happening in the seawater greenhouse was far more complex. Moreover, using manual methods would be time-consuming and error-prone and might not produce easily-understood data.

THE SOLUTION

Paton and his team decided to apply modern simulation methods, using MATLAB and Simulink. The Simulink model would be used to identify how the greenhouse could best be controlled and its design improved. It would also show the team how the design would work under various climatic conditions.

Gathering Data

The physical processes to be modeled included ventilation, evaporation of water and cooling of air, solar heating, and condensation of fresh water. Data was derived from previous laboratory experiments and British Meteorological Office records for Tenerife (including wind speed and direction, relative humidity, and solar radiation).



MATLAB analysis comparing conditions inside and outside the seawater greenhouse over a period of nine days. These graphs show the effect on the greenhouse of changing external temperatures, wind speed, and relative humidity.

One critical question was how much air would need to be forced through the greenhouse. This was answered by a computational fluid dynamics model, which determined the shape, structure, and optimization of the greenhouse's components, and by wind tunnel experiments.

Representing the Real System

Each physical process was then modeled within a Simulink block representing a physical object in the greenhouse, such as an evaporator or a condenser. The goal was to keep the model visually simple, embedding the technical details and equations in the Simulink blocks.

"The Simulink Look-up Table was particularly useful for representing the properties of humid air, which are complicated to work out using equations," says Paton. The dimensions of the greenhouse and of the physical objects were read from the MATLAB workspace using a graphical user interface created in MATLAB. This interface was also used to set process flow rates for air and water.

The completed blocks were connected as they would be in the real greenhouse, with the links corresponding to mass and energy fluxes. "Because there was an obvious visual correspondence to the real system, we ran less risk of making mistakes in the connections," says Paton. "Using conventional code-type programming, we would have been much more likely to make mistakes at this stage."

Optimizing the Model

The tricky process of optimizing the greenhouse model called for common sense and a little intuition. The team wanted to produce as much fresh water as possible, using minimal amounts of energy while maintaining a constantly cooled and humidified greenhouse environment. They ran multiple simulations to achieve optimal values for the

> *Thanks to our careful preparation at the design stage and the use of MATLAB and Simulink to model the physical processes involved, the performance of the seawater greenhouse in Tenerife was outstanding.*
>
> Charlie Paton, Light Works, England

many conflicting variables. Simulation results were displayed in a series of plots and graphs that showed key parameters over time, such as the quantity of fresh water produced, power consumption, humidity, air and water temperature, wind speed and direction, and internal air velocity.

Inside the seawater greenhouse.

The Tenerife Prototype

The Light Works team built a full-scale prototype greenhouse in Tenerife. The prototype enabled them to compare real, observed performance with that predicted by the model. The Tenerife prototype was equipped with 30 sensors measuring temperature, humidity, wind speed, solar radiation, and flow rate. Data on these variables, logged at ten-minute intervals over several months, demonstrated a strong correlation between actual and simulated performances.

The prototype validated the computer model, which can now simulate a whole year of greenhouse operation. Light Works is currently using the validated model to design and build seawater greenhouses in Oman, Morocco, and the Caribbean.

THE RESULTS

- **Rapid, reliable simulation.** Simulink allowed the team to simulate the performance of literally thousands of conceptual designs, avoiding a time-consuming, trial-and-error design approach. There was very good agreement between the performance predicted by the computer model and the actual performance of the prototype greenhouse in Tenerife.
- **Energy-efficient new technology.** The seawater greenhouse costs less to run than a conventional desalination system. One kilowatt of electrical power will produce about 600 kw of cooling, and electricity is required only for the process controller, pumps, and fans.
- **An award for architectural design.** The seawater greenhouse won the first Design Sense Award in October 1999 and has attracted interest from governments, businesses, and private individuals throughout the world. ■

To find out more about Light Works, call **+44 20 7 249 3627**

APPLICATION AREAS

- Modeling and simulation
- Environment
- Earth and planetary sciences

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- MATLAB®
- Simulink®

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