CHEMICAL WARFARE AT WORK

Don't trust anything or anyone—not your computer, your colleagues, the phone, the fax or the furniture. They're all out to get you. *Howard Baker* reports

YOU know the feeling—you've had a nice relaxing weekend at home, but now Monday's rolled around again and it's time to face the office. By mid-morning you're tired and irritable, you can't concentrate, your throat is dry and your nose is blocked. Then your telephone goes all crackly and dies at the precise moment that your computer and fax machine pack up. Maybe you are just being paranoid, but it really feels as though your office is out to get you.

And it seems you could be right. The modern office, freshly painted and stuffed with synthetic furniture and carpets, is emitting a noxious chemical soup which can attack humans and machines alike. People are also adding their own nasty ingredients to the mix and machines are stirring things up too. It is all-out indiscriminate chemical warfare—the furniture is affecting the fax machine, the photocopier is picking off people, humans are harming computers... and all the combatants are gassing themselves at the same time.

'The chemical soup is a prime suspect for...'

This soup is a prime suspect for causing the headaches, lethargy, and all manner of bodily irritations experienced by some office workers—symptoms of the widely-suffered but poorly-understood condition "sick building syndrome". Yet the trail of destruction doesn't stop there. The soup can swamp the circuit boards in office equipment, causing telephone systems, computers and fax machines to wither from an electronic form of sick building syndrome—or even crash completely. So they are not going on the blink to spite you—they are suffering with you.

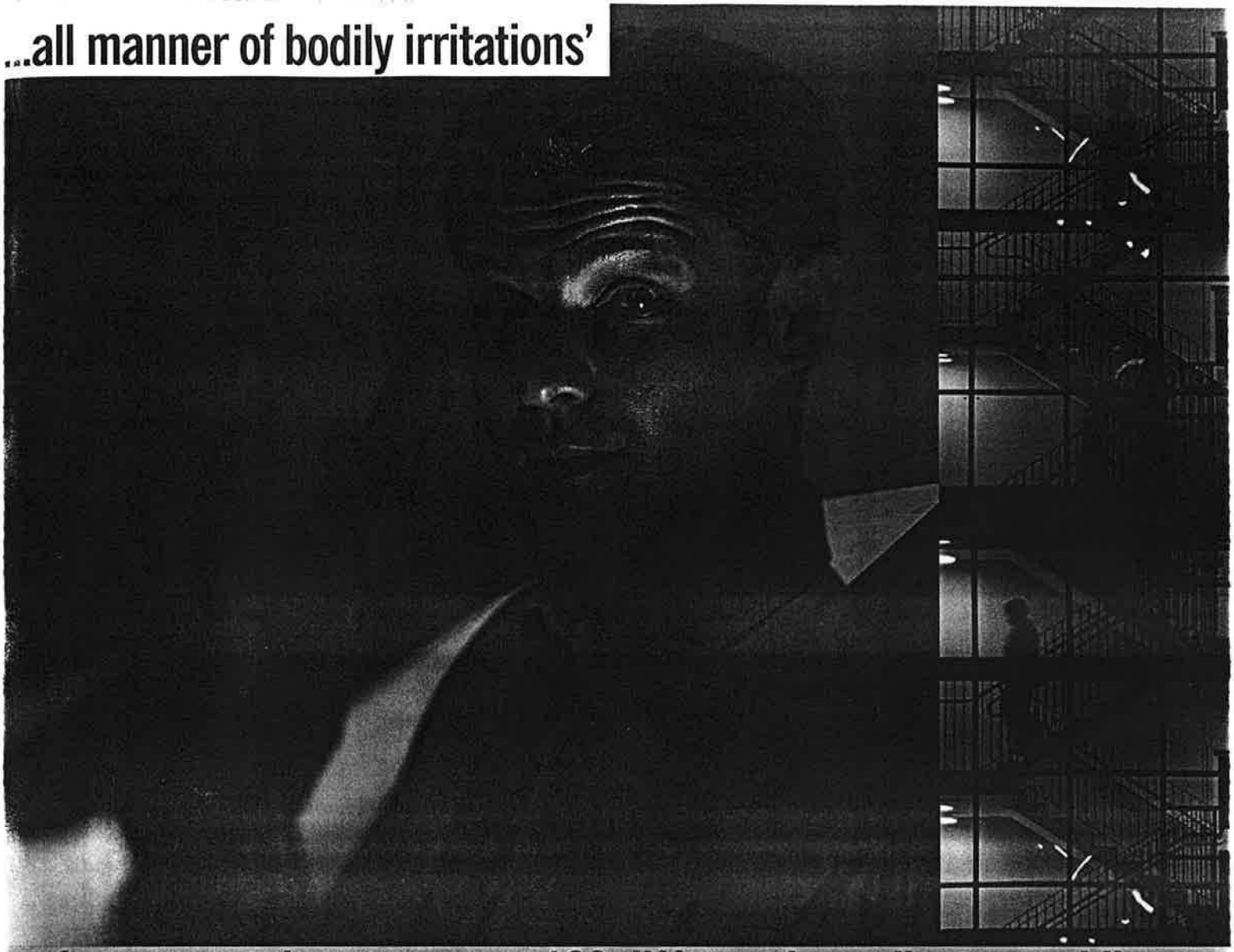
Chemists had suspected for a while that the chemical nasties responsible for brewing up such a destructive gumbo were volatile organic compounds (VOCs). But until now, finding out why they have had such widespread effects has evaded researchers. Recent studies suggest a more complex cookery at work—something is needed to stir up the soup. It appears when individual VOCs mix with other reactive chemicals such as ozone, the resulting brew can be more damaging to machines than the original chemicals. And evidence suggests it might knock people for six as well.

Airborne assault

VOCs have been known about for more than twenty years. They, along with everything from poor lighting and ventilation to a badly designed office, have been fingered as possible contributing factors to sick building syndrome. More than 250 different VOCs have been identified in office air. Floor tiles, carpets, paint, varnish, new furniture, glues and wall coverings all emit a complex mixture of organic compounds. They range from small, reactive compounds such as formaldehyde, to large molecules with long chains of carbon atoms such as decane and various glycol esters (see Diagram).

People began to adopt methods to

...all manner of bodily irritations'



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reduce the level of VOCs in offices in the 1970s. But matters were made worse by the oil crisis of 1979, which provoked changes in building regulations around the world. Office designers trying to save energy added extra insulation materials, which emit VOCs, and slowed down air conditioning systems, which reduced the fresh air coming in to offices. Emissions from synthetic materials used to make office furniture also stifled attempts to further reduce VOC levels.

And last year Charles Weschler of Bell Communications Research, otherwise known as Bellcore, in Red Bank, New Jersey, realised that there is another major source of VOCs—people themselves. Although people were already known to emit VOCs, their contribution to the office soup hadn't been measured. Weschler found that the total concentration of VOCs in densely occupied offices was more than twice that in telecommunications buildings where only a few people work. Humans are contributing to the problem in a big way.

GCAS/ Photonica

For example, freshly dry-cleaned clothes emit a stream of trichloroethane, the solvent used by dry-cleaners. On a more personal note, after a good wash and freshen-up our bodies give off the scent molecules and other chemicals left by shampoos and soaps, as well as the pleasant smelling chemicals in deodorants and perfumes such as limonene, terpinene, camphene and alpha-pinene. Some perfumes contain as many as 100 different ingredients providing potent additions to the office soup. On top of this, we contribute acetone and isoprene which our bodies produce naturally.

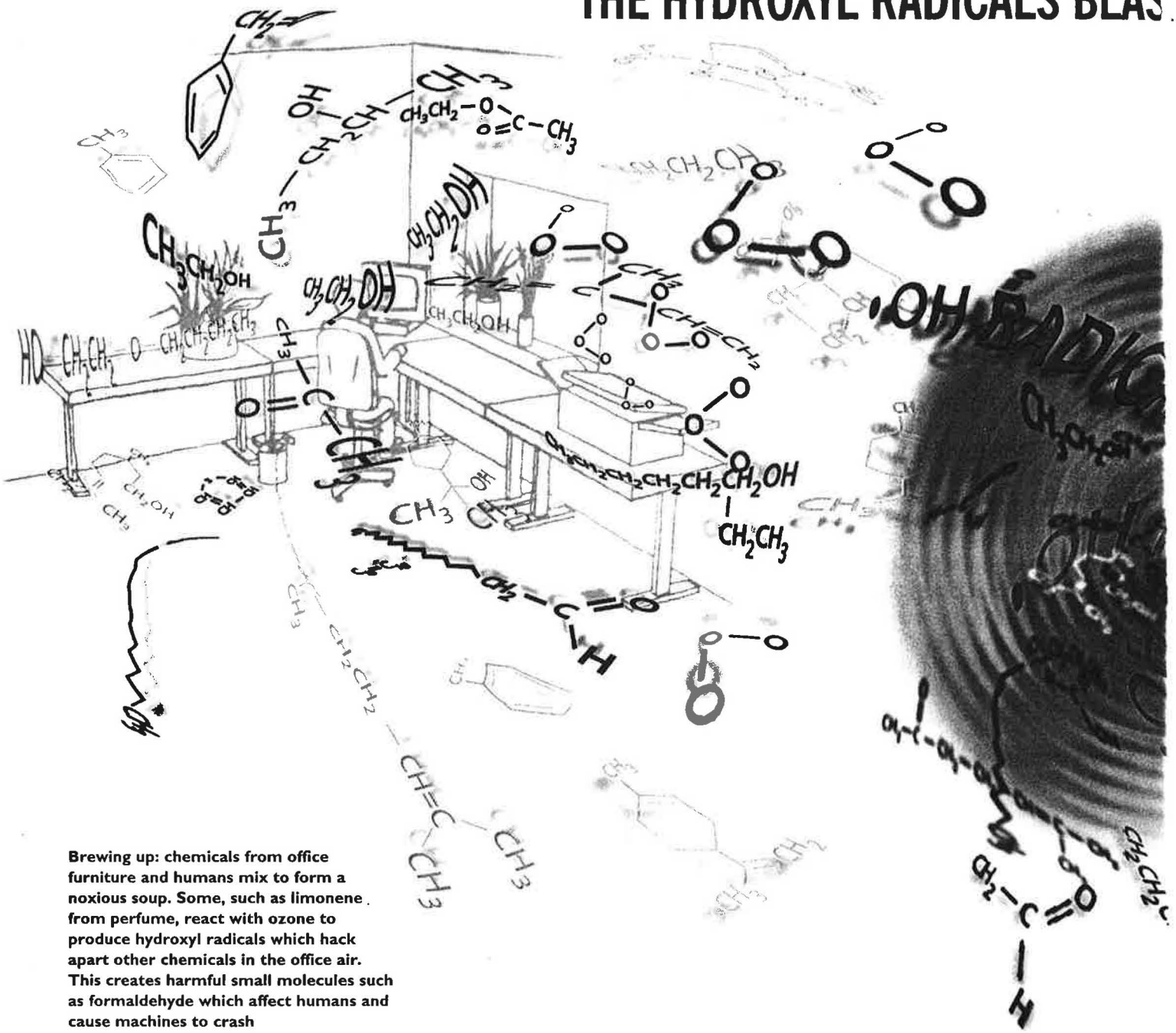
But hang on—why is Weschler, a researcher for a telecommunications company, so concerned about VOCs and their sources? Well, VOCs are the prime suspect for causing costly failures in telephone exchange boards and other electronic equipment. Weschler has shown that circuit boards suffer from their own form of sick building syndrome due to VOCs. In diagnosing the cause of the problem, he has uncovered a whole new, highly reactive dimension to the chemical soup—one that could also be responsible for the symptoms in humans.

Indoor smog

The key culprits, Weschler found, are wildly destructive species known as hydroxyl radicals. A hydroxyl radical is composed of one hydrogen and one oxygen atom, on which sits a lone electron that is desperate to find a partner. This electron is the cause of the radical's extreme reactivity. Hydroxyl radicals react quickly and voraciously with most compounds in the atmosphere, says Weschler, and play a major part in forming photochemical smogs in polluted cities. But until now, people assumed there were virtually no radicals indoors.

However, Weschler and colleague Helen

'THE HYDROXYL RADICALS BLAS



Brewing up: chemicals from office furniture and humans mix to form a noxious soup. Some, such as limonene from perfume, react with ozone to produce hydroxyl radicals which hack apart other chemicals in the office air. This creates harmful small molecules such as formaldehyde which affect humans and cause machines to crash

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Shields recently found that as many as a trillion hydroxyl radicals can be present in every cubic metre of indoor air. Although this is lower than a polluted city centre during daytime, it is higher than outdoor values at night and, more importantly, much higher than they expected to find in office air. So where are all these radicals coming from?

Weschler says that the radicals are formed by reactions between ozone—produced by equipment such as photocopiers and sucked into the office from outdoors—and VOCs given off by people. "These VOCs contain double and triple bonds," he says, "which react with ozone molecules." The hydroxyl radicals produced by these reactions then blast apart all the other VOCs around them. This is where the trouble really starts for any circuit boards in the vicinity.

When the radicals break VOCs apart, they create harmful chemicals including formaldehyde and other small aldehydes, ketones, acetic acid and nitric acid. These small compounds are more reactive than their "parent" VOCs, and play a key role in one form of damage to electronic equipment studied by Weschler.

Nitric acid molecules go on to react with other compounds and form nitrate salts, which can soak up water. The nitrates, along with other airborne particles, settle on circuit boards to form a layer of water-absorbing, or "hygroscopic", dust. When the dust is dry, it normally doesn't conduct electricity, and so doesn't pose much of a threat to the circuitry. The problems start when the humidity rises. The dust absorbs water from the atmosphere, creating an ionic solution which forms a conducting bridge between components. Electrical signals from the circuit board start to pass into the solution, giving "soft" errors such as a misplaced 1 or 0 in a digital signal. If the boards form part of a telephone exchange, the problem rears

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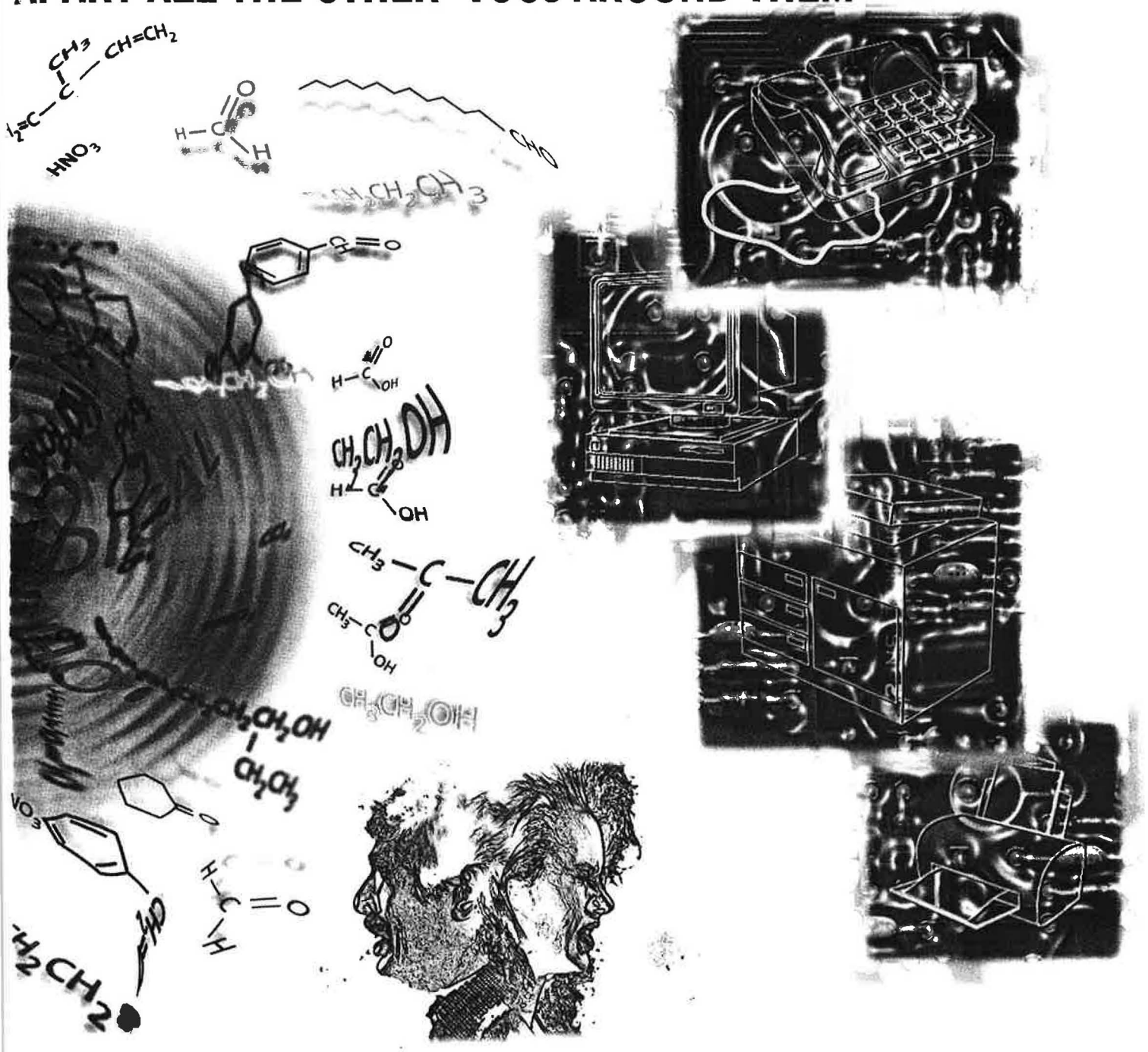


ndoor air'

its head as crosstalk or line noise. Eventually, the boards can short out and the entire exchange can fail.

One telephone exchange in California experienced just such a disaster, says Weschler. It was a stormy night and a lightning strike had damaged the ventilation system for the exchange. The humidity in the building rose until it hit 80 per cent, at which point the dust covering the circuit boards responsible for 20 000 telephone lines turned into a conducting solution and the entire system blew. Total cost: $250 000.

But damage wrought by the chemical soup doesn't stop there. Weschler and Shields have identified a second route to disaster which depends on the VOCs alone.

Bad vibrations

Many compounds in the soup are adsorbed by the gold and other precious metals used to coat contacts on circuit boards. "Thanks to cooling fans, traffic outdoors and other vibrations, there is always a little motion—friction—between mated connectors," Weschler says. "There is also electrical potential across the connectors." This mix of friction and electrical potential causes the VOCs to react with each other, forming what is known as a frictional polymer.

The polymer produces resistance between contacts and prevents current flowing around circuit boards. And so the boards tend to blow. "The chances are very high that one or more components will fail over the intended lifetime of a board due to frictional polymers," says Weschler. "This lifetime can be anything from 6 months to 5 years." He estimates that frictional polymers and nitrate dust have cost American telecommunications companies a minimum of $100 million over the past ten years.

Fortunately, there are early warning signs to tell companies if the circuit boards in their offices are suffering in a

VOC soup before they blow completely. Sometimes an apparently faulty circuit board starts to work again when it is unplugged and plugged back in again. Engineers call this a "no-problem-found" job. Frictional polymers are bound loosely to the boards, so a smart tap can be enough to clear the problem, in the same way that a thump to an errant TV or video often fixes the fault. "Equipment may behave erratically at high relative humidities due to the presence of water-absorbing contaminants too," says Weschler. So the warning lights for VOC-related trouble ahead are an increase in the number of "no-problem-found" scenarios and occasional board failures.

Unfortunately, unless your office is packed with electronic equipment, such circuit board failures are likely to go unnoticed among the everyday problems that crop up. For most offices it is cheaper to replace a few crashed computers than tackle the VOCs. "It is not cost-effective to look at air pollution unless you are a buyer of huge amounts of electronic equipment," says Weschler.

If Weschler's notions about hydroxyl radicals and VOCs have helped to explain how machines suffer in the office, they have simply added to the uncertainties of how humans respond to airborne pollutants. After 20 years, scientists have yet to find any simple relationship between the amounts of VOCs in offices and their effects on our health. The area is hellishly complicated: the mixture of chemicals in air changes hour by hour and people have a range of susceptibilities to them. Scientists are still arguing about which VOCs to measure and how to measure them.

"Finding effects in machines is easy," says Gary Raw of the Healthy Building Centre at Britain's Building Research Establishment in Watford. "There are no ethics panels to stop you exposing them to high concentrations of VOCs." But as he points out: "You can't do that with humans." The most that scientists have been able to do is isolate people in chambers and expose them to low levels of VOCs. In the mid-1980s, Lars Mølhave, head of the Institute of Environmental and Occupational Medicine at the University of Aarhus in Denmark, showed that people known to suffer from sick building syndrome suffered eye and airway irritation, and attention deficits after breathing in a cocktail of 22 VOCs emitted from building materials. Subsequent experiments on healthy people found that the higher the concentration of VOCs, the worse the symptoms.

Menace in the mix

Strangely, although these experiments showed that VOCs have real effects, each of the VOCs in the cocktail was at a concentration one-tenth to one-hundredth the level defined as safe for occupational health purposes, so none of them should have been harmful. One explanation for this, says Raw, is that "compounds with similar effects have an additive impact". The effect of the mixture might even be greater than the sum of the effects of its parts. "The problem is that we know practically nothing about mixtures," says Maurizio de Bortoli, senior scientist at the Environment Institute at the European Union's Joint Research Centre at Ispra, Italy.

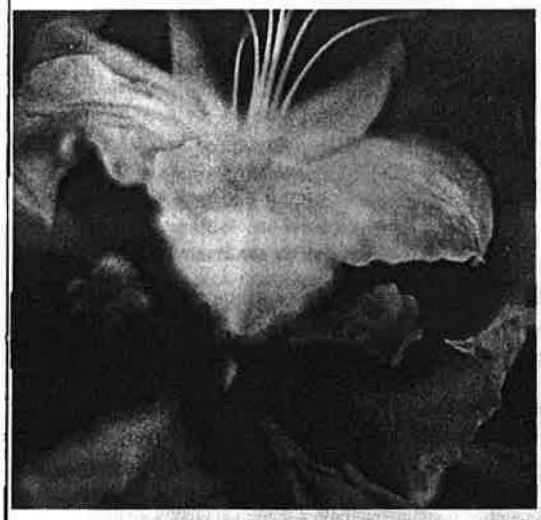
In the office itself, matters get still more complicated. Research has been hampered because there is no standard list of chemicals to measure. In the 1980s, a measure called total volatile organic compounds (TVOC) became a marker for indoor air quality. This measures the total mass of an ill-defined ragbag of chemicals in a cubic metre of air. Through the 1980s scientists used TVOC uncritically, says Peder Wolkoff, senior researcher at the Danish National Institute of Occupational Health in Copenhagen. "They believed for a long time that VOCs were the cause of eye and respiratory tract irritation and may be the

'STOCK UP ON SPIDER PLANTS'

Greens eat soup

WHEN people refer to chemical treatment plants, they tend not to mean the potted, green variety. But after 20 years of research, retired NASA scientist Bill Wolverton has shown that at least 50 different house plants gobble up harmful VOCs from the office soup.

Azaleas, rubber plants, tulips, poinsettia and bamboo palms can all remove formaldehyde from the atmosphere. The areca palm is best for dealing with toluene and the lady palm sucks up ammonia. While each plant has its own preferred diet, Wolverton says that many of them can eat a range of VOCs—the peace lily, for example, removes acetone, methanol, ethanol, benzene, trichloroethylene and ethyl acetate from the atmosphere, as well as formaldehyde and toluene. These chemicals—which might otherwise trigger sick building syndrome and cause electronic equipment to crash—serve as food for the microorganisms growing on or around the plants' roots.



Wolverton first discovered that house plants could eat up VOCs in 1980, while studying the 300 or so VOCs found in the spacecraft air from Skylab missions. A build-up of these chemicals could pose problems in a self-contained life-support system, such as a manned Moon base, but Wolverton showed that air quality could be controlled by cultivating the right plants. In 1989, using philodendrons and golden pothos, he kept the air virtually free of VOCs in NASA's Biohome experiment—a tightly sealed room designed to mimic a space station or Moon base. Significantly, without the plants the occupants of the Biohome, which is now known as the Lunar 1 Module, experienced breathing problems, streaming eyes, sore throats and blocked-up noses—all symptoms of sick building syndrome.

In the same year, the Plants for Clean Air Council, based in Davidsonville, Maryland, was formed to promote work such as Wolverton's. Since then Wolverton has identified 50 plants that can vacuum up VOCs, and earlier this year published a book entitled *How to grow fresh air*. He has even turned his own home into a self-cleaning ecosystem.

So to combat those streaming eyes, sore throats, skin irritations and crashing computers, perhaps the simplest thing to do is pay a visit to the local garden centre. Stock up on spider plants, tulips, banana plants, philodendrons and lilies, and the office could become a much more pleasant place to work.

cause of the whole problem of sick building syndrome," he says. But it became clear that TVOC told them nothing about the health effects of VOCs. "TVOC measures what is easiest to measure, not what's most important," says Raw.

De Bortoli and his colleagues at Ispra are coordinating a European attempt to bring order to this chaos. In a report to be published later in the summer, they recommend a protocol for measuring 60 VOCs that they reckon are the most toxic to humans. This measure, says de Bortoli, should allow useful comparisons to be made and, it is hoped, shed new light on the health effects of VOCs.

'If you are wearing perfume or aftershave, blame it on yourself'

Meanwhile, Wolkoff is championing the idea that reaction products of VOCs may be doing the damage. He reiterates that many VOCs are found in air at concentrations 1000 times below the levels at which they start to become a nuisance. But he suggests they react with ozone to create hydroxyl radicals which react with VOCs to produce more irritating chemicals such as formaldehyde and formic acid, along with intermediate chemicals that are radicals themselves. These have never been tested for their irritation potential, but this is next on Wolkoff's list of experiments.

In one respect, Weschler's and Wolkoff's work is bringing indoors chemical reactions that have been known to cause problems outdoors. This is the chemistry of photochemical smogs, which have blighted cities such as Los Angeles for decades and are now a problem in London. VOCs and oxidants, including ozone and nitrogen oxides, play a central role in these smogs. "We've long thought that no reactions took place in buildings because there's no sunlight," says de Bortoli. "But the early work suggests that reactions are taking place."

There is also another well-known outdoor pollutant implicated in the VOC story—tiny particles that can act as vehicles for VOCs which can then react with ozone or nitrogen oxides to create even more irritating compounds. Raw points out that these particles are likely to stay in the mucous membranes of the eyes, nose and airways for long enough to deliver a higher than expected dose of the compounds.

And as if there weren't enough sources of VOCs, Charlene Bayer, director of the Indoor Environment Research Program at the Georgia Institute of Technology in Atlanta, says that microorganisms can also add small amounts of potent compounds. Bayer and microbiologist Sydney Crow of Georgia State University have collected numerous samples of fungi from "sick" buildings. When grown in the lab, these fungi emit VOCs including hexane, acetone, and even the carcinogen benzene.

Fighting back

So do we have any defence against the potentially devastating effects of VOCs? Following Weschler's research, Bellcore issued guidelines to US telecoms companies to help them prevent circuit board failures—guidelines that would improve office conditions for humans as well. These include using high ventilation rates for rooms containing electronic equipment, positive pressure in important rooms, and using charcoal filters to reduce levels of ozone, and—obviously—avoiding products that emit large amounts of VOCs. Unfortunately, applying these guidelines to most existing offices would be expensive, if not impossible. However, there is potentially a cheaper, organic alternative—use plants to eat up the VOCs (see "Greens eat soup").

But if, despite being surrounded by a forest of foliage, you are still suffering the effects of the soup, at least you know there's a chemical cause of your streaming eyes, itchiness and irritability. So when the computer crashes unexpectedly, or the phones fail, or the fax machine gives up the ghost—blame it on the carpets; blame it on the furniture; blame the photocopier; and if you are wearing perfume or aftershave, blame it on yourself. Give the hapless machine a kick— it might just do the trick. And then go and get a breath of fresh air. □

Howard Baker *is a science writer based in London. Additional reporting by Stephen Hill and Jeremy Webb.*

Further reading: How to grow fresh air *by Bill Wolverton, Penguin, 1997.*
"Volatile organic compounds–sources, measurements, emissions and the impact on indoor air quality" by Peder Wolkoff, Indoor Air, *1995, Supplement 3.*

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