Mitigating exposure to cooking emissions in kitchens of low-middle income homes

A guide for home occupants, owners, builders and local councils

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Glossary

Air Fryer: A small countertop convection oven designed to simulate deep frying without submerging the food in oil.
Air ventilation: Natural or forced movement of outdoor air into an indoor space. It controls indoor air quality (IAQ) by diluting and displacing indoor pollutants. It also regulates indoor temperature, relative humidity, and air current for thermal comfort. Adequate ventilation can be achieved naturally by opening the doors and windows, mechanically with extraction fans, or both.
Builders: Entities responsible for constructing buildings in cities, often referred to as real-estate developers or construction contractors.
Carbon dioxide (CO_2): A gas emitted by the combustion of fossil fuels and biomass, naturally exhaled by humans, and is an indicator of ventilation adequacy in indoor environments. High CO_2 levels indicate inadequate ventilation and is associated with adverse cognitive effects, such as a reduced ability to concentrate.
Citizen science: Scientific research undertaken by members of the public. Citizen science incorporates inclusion (e.g. community involvement in planning research), collaboration (e.g. between the community and researchers) and reciprocation (e.g. resulting in presentations by citizen scientists to their communities).
Coarse particles: Particulate matter with a diameter of 2.5 to 10 micrometres; also known as $PM_{2.5\text{-}10}$ Airborne coarse particles are predominantly generated by non-exhaust sources, such as fugitive dust (i.e. particulate matter generated or emitted to the air by the wind or mechanical disturbances).
Cooking fuel: A fuel such as natural gas, liquified petroleum gas (LPG), kerosene, ethanol, and biomass-based fuel (e.g. charcoal and wood) that is consumed to heat food during cooking.
Cooking stove: A device that burns fuel or uses electricity/solar (or any kind of) energy to generate heat inside or on top of the appliance to cook food.
Dispersion: Aerial distribution of air pollutants after being emitted from a source.
E-cooking: Cooking with electricity (i.e. use of electricity-powered appliances for cooking).
Extraction fan: A fan used to remove stale air or fumes from an enclosed space, such as kitchens.
Fine particles: Particulate matter of less than or equal to 2.5 micrometres in diameter; otherwise called $PM_{2.5}$. Fine particles are highly harmful air pollutants because of their small size, enabling their deep percolation into the respiratory system while breathing, causing various heart and lung diseases. They are predominantly generated from combustion activities such as the burning of solid, liquid or gaseous fuels.
Fuel stacking: Use of multiple fuel sources, often both polluting and clean, in a household. Instead of fully switching from one fuel type to another, households often use a combination of fuels.
Home occupants: Persons living in a home, either by possession or rent.
Homeowners: Persons owning a house. They may design or participate in the design of their home and have the authority to make any structural changes they desire.
Indoor air quality (IAQ): The quality of air within enclosed spaces, such as homes, offices and vehicles. Poor indoor air quality arises from the presence of particulates (typically PM_1, $PM_{2.5}$, PM_{10}) and gaseous pollutants (such as nitrogen dioxide, formaldehyde and volatile organic compounds). Indoor air quality influences the comfort and health of building occupants. Relevant national and international bodies (such as the World Health Organization) offer guidance for air filtration and ventilation to ensure adequate indoor air quality.
Local council: A body of people elected or appointed to manage a town, county or district. Also referred to as a municipality, local government, city council, local authority/assembly, mayor's office and town council.
Passive occupancy: The presence of individuals within a certain premise who are neither directly involved in nor contributing to the core activity such as having toddlers in the kitchen.
Particulate matter (PM): A mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope.
Thermal comfort: One of the indoor environmental factors, mainly determined by temperature, relative humidity, and air movement, that affect health and human performance.

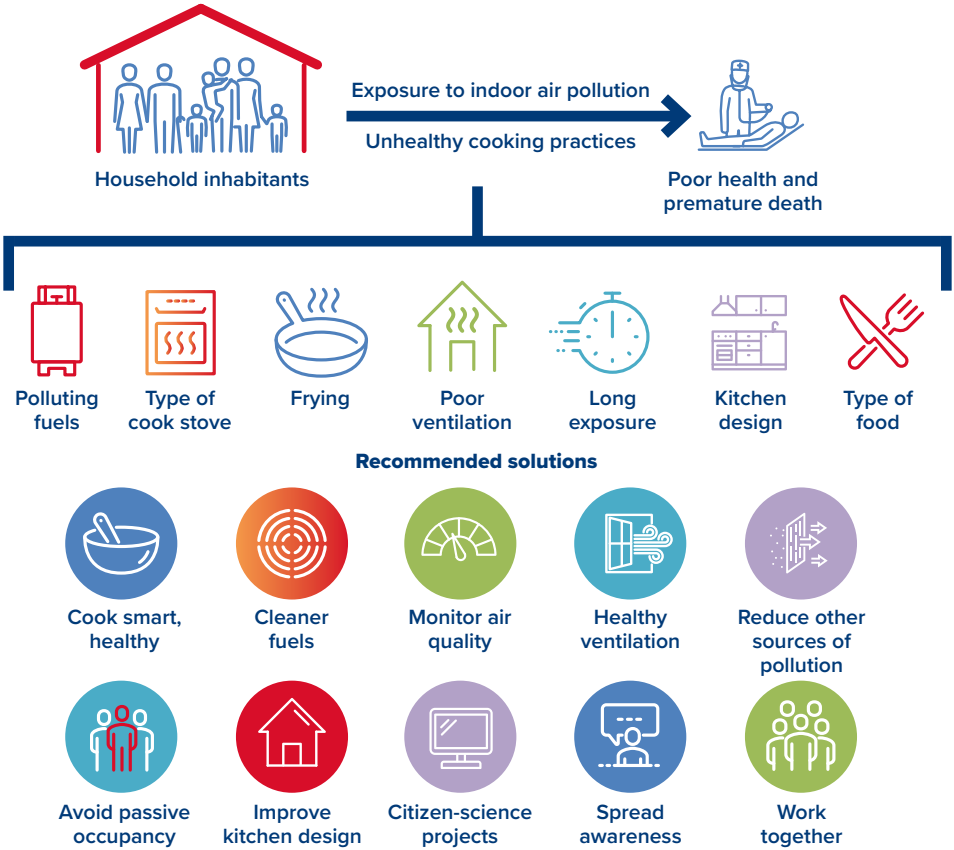
Introduction

Approximately four million people die prematurely from illnesses attributed to indoor air pollution generated by the use of highly polluting fuels such as charcoal or wood for cooking [1]. Impacts may range from acute to chronic health effects, depending on age, sex, time of exposure, distance from the kitchen, ventilation conditions, and fuel type. Poor indoor air quality may cause acute illnesses, such as headache, fatigue, drowsiness, nausea, dyspnoea, wheezing, confusion, anxiety, nose and throat ailments, and stupor (carbon dioxide narcosis) [2,3]. The associated chronic diseases include heart diseases, pneumonia, stroke, lung cancer, and chronic obstructive pulmonary disease [1]. In some cases, exposure to such indoor air pollution is also linked to the development of cataracts. A pregnant woman's exposure to indoor air pollution can increase the risk of their infant being premature or of low birthweight.

In-kitchen air quality is affected by many factors, such as the cooking fuel type, cooking method (e.g. frying, boiling), food type, cookstove type, room structure, ventilation conditions, geographical and meteorological conditions, and exposure time [4,5,6,7,8]. Typical homes in low- and middle-income countries experience poor in-kitchen air quality, attributable to using polluting fuels [9] (e.g. biomass, kerosene, coal), poor ventilation, and poor cooking practices.

Cooking for a long period using polluting fuels in small poorly ventilated kitchens exposes inhabitants to a range of pollutants, impairing their health. Most indoor air quality guidelines focus on schools [10,11], while some are targeted at professional practitioners and planners [12,13]. Other guidelines include fact sheets on the air quality risks associated with cooking [14]. Complementing previous works, this booklet provides practical suggestions for frontline users and decision-makers based on scientific findings in low- and middle-income homes.

Using an active control system (e.g. emission-free cooking with solar-powered stoves with a battery pack or e-cooking powered by grid electricity) can be an effective solution and constitutes the best practice. There are risks associated with emission-free cooking (disconnection from solar-powered systems due to storage system issues) and e-cooking (potential brownouts from grid systems), but these issues can be overcome with improved supply chains and electricity subsidies [15]. Because policies are typically slow-paced and difficult to implement, practical and straightforward mitigation measures are essential to reduce pollutant concentrations and mitigate in-kitchen exposure (e.g. improving kitchen ventilation through natural and mechanical means during cooking). A holistic approach is required from those directly contributing to and those affected by indoor cooking pollution to make a significant difference at the grassroot level. Hence, a successful exposure mitigation strategy requires multifaceted actions that target homeowners, occupants, builders, and local councils.



The above figure reflects the drivers behind indoor air pollution exposure in the kitchen microenvironment that puts the health of house inhabitants at risk. The figure then summarises recommended actions to mitigate exposure.

The aim of this guide is to translate scientific research into easy-to-implement precautionary measures and actions adoptable by homeowners, builders, and regulatory bodies to reduce human exposure to in-kitchen pollution in homes.

Recommendations are based on contemporary scientific evidence and may, therefore, evolve over time as new evidence emerges. The uniqueness of this document is its holistic approach, targeting the key receptor groups; homeowners, occupants, builders, and local councils simultaneously. It uses findings of relevant research [1,9,16,17] and numerous review studies [15,18,19,20,21,22,23,24]. The guide also builds upon the studies carried out by a group of international researchers from high-, middle- and low-income countries who collaborated on the 'Clean Air Engineering for Cities (CArE-Cities)', 'Clean Air Engineering for Homes (CArE-Homes)', and the 'Knowledge Transfer and Practical Application of Research on Indoor Air Quality (KTP-IAQ)' projects.

Most recommendations in this guide are centred on the mitigation of airborne fine and coarse particles, the classes of air pollutants with the most severe impact on human health [24]. Other recommendations involve carbon dioxide levels, ventilation, and thermal comfort conditions in homes. However, the information may apply to other harmful pollutants resulting from cooking, such as carbon monoxide, nitrogen oxides, volatile organic compounds (e.g. formaldehyde), polycyclic aromatic hydrocarbons, and persistent organic compounds (e.g. dioxins), and also to modern homes within and beyond low- and middle-income countries.

Specifically, this guide focuses on in-kitchen pollution resulting from daily cooking in homes of selected low- and middle-income countries. Detailed descriptions or recommendations regarding indoor (e.g. kitchen) air quality and related health effects, as presented in prior guides [11,12,13], are beyond the scope of this publication.

This document offers 10 generic and 10 specific recommendations for three target audiences: homeowners, builders, and regulatory bodies. This guide recognises that local realities may render some of the suggestions and actions difficult to implement in the short term, especially where new technologies or investments need to be made at a larger scale. This includes existing homes, such as those with limited opportunities for structural change or poor households in rural and urban slum areas that do not have a designated kitchen. Our hope is that the umbrella of recommendations provided here is relevant for countries at different stages of action towards reducing exposure to indoor air pollution. Therefore, implementing as many recommendations as reasonably possible would benefit the home occupants and the community. It may also serve as a reference document for those developing awareness-raising campaign material, adapted for local considerations. It can help home occupants in adopting simple precautions to reduce their contribution and exposure to in-kitchen air pollution. Because food preparation also contributes to healthy eating, this guide also complements the WHO recommendations [25].
These recommendations are not formatted in a particular order of priority, significance, or impact because of a lack of evidence of the comparative impact of each influencing action. In any case, a holistic approach is needed to tackle the indoor air pollution problem.

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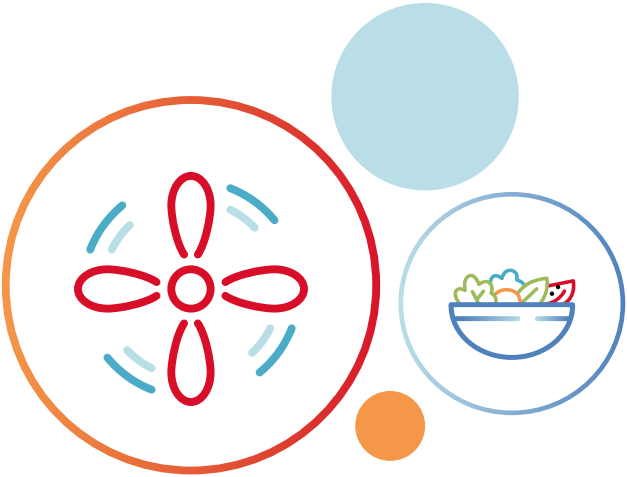
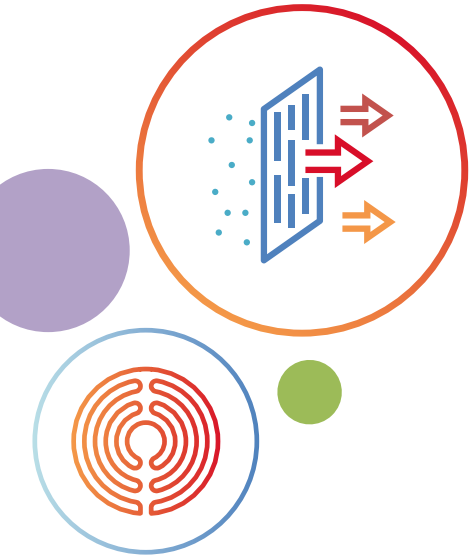


General recommendations

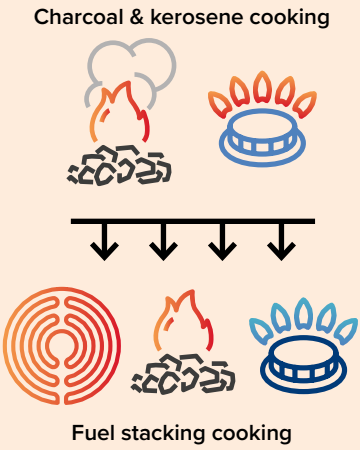


Cook smart, cook healthy

Spreading awareness amongst home occupants about the health risks of cooking fumes is imperative. Understanding such risks might prompt home occupants to adopt efficient cooking methods and techniques that reduce the release of fumes; for example, by reducing cooking duration and adopting healthier food options and cooking styles. Distribution and training in the use of devices such as electric pressure cookers and rice cookers can help to reduce cooking duration.

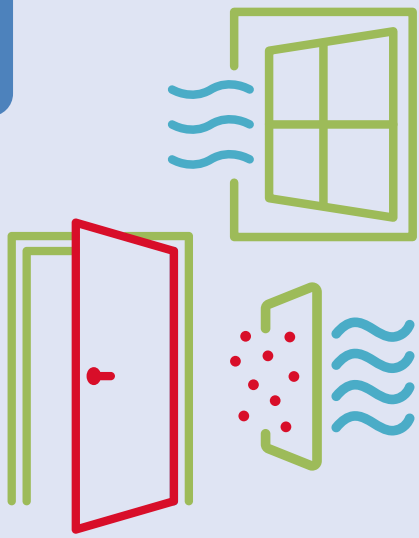
Promote cleaner fuels

The threat of climate change is driving national and global agendas toward cleaner fuels and renewable energy. The shift should not be limited to the industrial and transport sectors. The use of polluting fuels (such as charcoal and kerosene) for cooking should also be phased out. This requires a change in 'fuel stacking' practices, where households combine the use of clean and polluting fuels. While fuel stacking cannot be completely eliminated, measures can be taken to increase opportunities for households to use clean fuels. This includes making clean fuels and their compatible cookstoves more accessible and affordable. Direct human exposure to indoor emissions from such fuels contributes to significant health impacts.



Adopt healthy ventilation practices

Promoting healthy indoor ventilation by opening windows and doors during pollutant-emitting activities (e.g. cooking and cleaning) can reduce occupant exposure and protect health. Installing functioning extractor fans or other low-cost home-made air purification technologies such as the Corsi-Rosenthal box in kitchens would also limit the build-up of pollutants and steam, reducing health risks.



Consider monitoring in-kitchen air quality

Being informed is the first step in taking corrective actions. Home occupants can reduce exposure to air pollution by understanding the levels of indoor pollutants. Carbon dioxide levels are indicative of ventilation conditions and demonstrate the accumulation of indoor air pollutants. Monitoring easily measurable indoor air quality parameters such as particulate matter, carbon monoxide or carbon dioxide is a practical preventive safety measure.

Consider other sources of in-kitchen air pollution

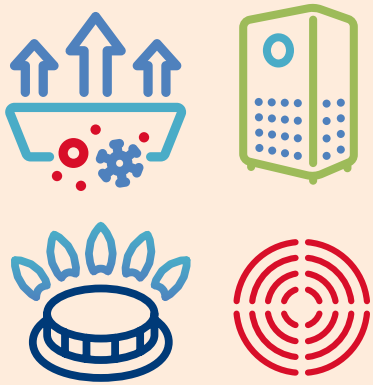
Homeowners should be made aware of other sources and activities that contribute to indoor air pollution – dusting, cleaning with cleaning products, smoking, dust resuspension, spraying mosquito repellent, burning incense or candles, painted surfaces, and heating. Precautions such as providing adequate ventilation and cleaning regularly to avoid the build-up and resuspension of dust should be taken.

Avoid passive kitchen occupancy

Because cooking emissions pose a risk to human health, passive occupants (people not involved in cooking such as children, elderly people, pregnant women and those with respiratory allergies or diseases) should avoid the kitchen during cooking. Those who cook should leave the kitchen whenever no supervision is needed to reduce their exposure to cooking emissions.

Consider indoor air quality when designing new homes

Regulatory bodies should provide and enforce green building codes that consider improved indoor air quality, such as allocating larger volumes for kitchens, including more/wider windows and balconies, installing indoor air quality monitoring devices (e.g. carbon dioxide monitors), installing suitable air ventilators (e.g. cooker hoods/extractor fans), installing chimneys for open and ventilated kitchen designs and providing cleaner fuel connections (especially natural gas and electric cooking), and setting up compulsory training sessions for building designers.



Spread awareness on healthy kitchen practices

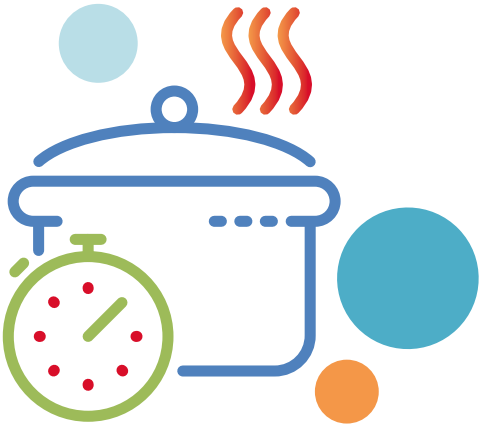
Indoor air pollution and strategies for mitigation should be part of national awareness campaigns with a special focus on people more involved in household activities. For example, the fundamental scientific, behavioural and technical considerations are reinforced as part of practices recommended in this guide, to help protect the health of homeowners. The increasing availability of affordable indoor air quality monitoring devices could support relevant hands-on exercises and home occupant-led experiments.

Involve everybody and work together

In-kitchen air pollution can be limited by active and/or passive control systems at the source (e.g. adjust the cooking style, use cleaner cooking fuels), receptor (e.g. reduce passive occupancy), and between source and receptor (e.g. improve the ventilation conditions). Exposure can also be mitigated through increased awareness and informed decision-making. Infrastructural considerations (larger kitchen volumes, more windows and possibly balconies) can also be implemented for new or refurbished homes. Therefore, a holistic approach, with communication and participation among home occupants, homeowners and builders, and local councils is crucial for overall change and effective exposure reduction.

Set up community science projects

Solutions can be co-designed with local communities and best practices can be implemented through direct collaboration via community science projects, e.g. collaborating with homeowners to co-design solution-oriented studies. Barriers to the adoption of clean fuels and cookstoves include affordability and a misconception of a change in the taste of food. Training programs and demonstrations can address misconceptions to reduce the use of polluting fuels. These programs can improve local awareness of in-kitchen air pollution exposure and mitigation measures among homeowners, builders, local councils, and regulatory bodies. Community science and participatory research can also enable individuals to share their experiences and/or concerns (e.g. healthy cooking practices) with researchers and policymakers for all- around actions for plausible adoption and implementation.



Targeted recommendations

Fact 1

Frying is the most particle-emitting activity that can contribute to more than 50% of the total harmful fine particulate matter emissions during cooking.

Adopting best practices that improve in-kitchen air quality, especially during frying, can significantly reduce occupants exposure to fine particulate matter emissions during cooking.

Home Occupants

- Improve ventilation during frying by opening the doors and windows and switching on the extraction fan (if available).
- Use air fryer where feasible to replace frying.
- Reduce the amount of food fried during cooking.
- Use alternative cooking methods such as steaming or oven roasting (where ovens are available and affordable) and increase the consumption of raw foods, when deemed safe.
- Protect your family and friends by keeping them out of the kitchen when you are frying so they inhale fewer damaging emissions.

Builders & Homeowners

- Install an extraction hood directly over the stovetop.
- Install a smoke alarm or carbon dioxide monitor to warn of pollution build-up.
- Ensure proper exit of exhaust emissions to avoid their re-entry to other nearby houses.

Local Councils

Spread awareness of the health effects of indoor air pollution, emphasising the importance of adopting best ventilation practices and reducing the use of high particle-emitting activities such as frying.

Fact 2

Shorter cooking sessions lessen in-kitchen air pollution.

Choose recipes and meals that take less time to cook to reduce overall in- kitchen pollution.

Home Occupants

Minimise cooking time by choosing simpler recipes and meals that involve less grilling and frying.

Builders & Homeowners

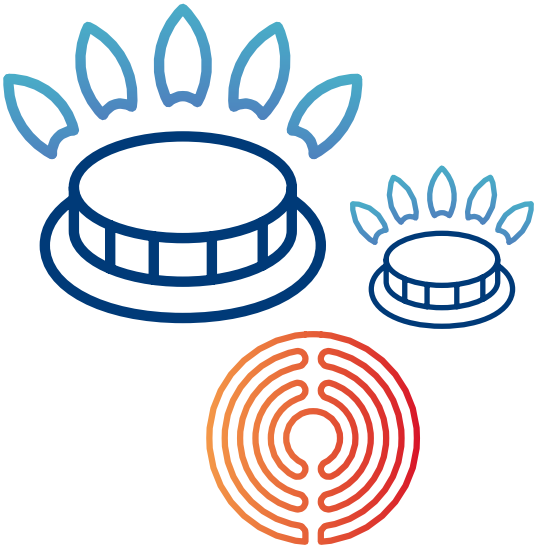
Include a safety sheet in kitchens that recommends healthy and safe cooking practices, such as reducing cooking duration when possible.

Local Councils

- Promote the benefits of simple, fast, healthy cooking and vegetarian diets.
- Promote and provide training in the use of devices such as pressure cookers and rice cookers, which can reduce cooking times, especially for lentils, beans, meat and rice.

Fact 3

Using natural gas and liquified petroleum gas (LPG) for cooking can reduce the average fine particle exposure during cooking by 1.3- and 3.1-times, respectively, compared with charcoal fuel. Kitchens using a combination of LPG and electric cookers observed a reduction in carbon dioxide levels of more than one-third compared with those using kerosene.



Use cleaner cooking fuels, such as LPG and natural gas, to substantially reduce exposure to indoor air pollutants.

Home Occupants

Choose cleaner cooking fuels and stoves, and maintain stoves and exhaust fans regularly to ensure proper ventilation efficiency.

Builders & Homeowners

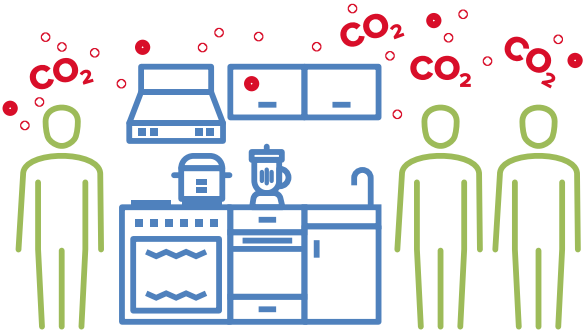
Design and construct homes with the necessary infrastructure (e.g. natural gas piping) and space to install stoves and ovens that use cleaner fuels.

Local Councils

- Phase-out harmful cooking fuels, such as charcoal and kerosene, by facilitating the adoption of alternative, cleaner fuels.
- Promote the use of improved cookstoves over traditional biomass stoves.
- Ensure that cleaner cooking fuels and cookstoves are readily available for use in all homes.
- Set a national agenda to use green fuels, such as solar-powered electric cookers, for cooking.
- Subsidise cleaner fuels and cleaner cookstove and oven options.

Fact 4

Inessential occupancy in the kitchen leads to unnecessary exposure to cooking emissions. It also increases the CO_2 levels, which can be over 7% higher with two or more occupants compared with one occupant.



Minimise passive kitchen occupancy during cooking to eliminate avoidable exposure and reduce carbon dioxide levels.

Home Occupants

- Prevent passive occupants (i.e. those not participating in cooking, such as children) from inhabiting the kitchen during cooking.
- Leave the kitchen during prolonged cooking sessions that do not require continuous supervision.

Builders & Homeowners

Design kitchens with a spacious area, such as a balcony or adjacent hallway, (where possible), so that toddlers can be supervised during cooking.

Local Councils

Spread awareness about the benefits of protecting occupants (especially children, the elderly, people with respiratory diseases, and other vulnerable groups) from exposure to cooking fumes.

Fact 5

Exposure to indoor carbon dioxide levels over 1000 parts per million (ppm) and airborne fine particles over 15 µg m^{-3} has been associated with negative health effects.

Monitor in-kitchen carbon dioxide levels and particulate matter to alert occupants to improve ventilation when levels exceed prescribed CO_2 and $PM_{2.5}$ levels.

Home Occupants

- Install a carbon dioxide monitor to alert occupants about the ventilation conditions when levels exceed permissible limits.
- Install a particulate matter monitor to alert occupants about the levels of indoor emissions from cooking and other relevant sources.
- Install a carbon monoxide monitor to alert occupants in case of fire or increased levels of gas.
- Monitors are available separately or together in one unit, showing values as a traffic light system (green, amber, red) in layman format, warning occupants to open the windows, switch on the extraction fan, or leave the room.

Builders & Homeowners

- Make provisions for installing carbon dioxide, carbon monoxide, and particulate matter monitors.
- Ensure kitchens have an effective ventilation system.

Local Councils

- Prepare local guidelines for indoor air quality monitoring installations.
- Subsidise and facilitate the installation of carbon dioxide, carbon monoxide and particulate matter monitors in indoor kitchens.
- Promote the benefits of monitoring to achieve good indoor air and ventilation among local communities.

Fact 6

Large-volume kitchens (>45 m³) exhibit approximately 30% lower carbon dioxide levels and 3-times higher ventilation rates than small-volume kitchens (<5 m³) because they allow cooking emissions to disperse more effectively.

Small-volume kitchens accumulate particulate matter and carbon dioxide concentrations more quickly than larger-sized kitchens because there is less space for dispersion.

Home Occupants

- If there is a choice, choose a home with a large kitchen.
- If a small kitchen is inevitable, install an extraction fan/hood to improve the volume of mixing air and minimise daily exposure.
- Open the windows and doors during cooking.

Builders & Homeowners

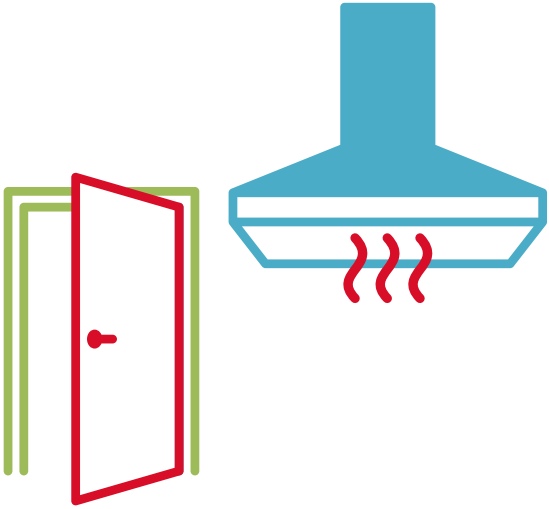
- Dedicate larger floor areas for kitchens in new homes or design higher ceilings to increase kitchen volumes.
- Ensure kitchens have large windows, doors, and/or balconies for improved ventilation and exhaust dissipation.
- Install the stove/oven close to the window to increase the rate of dissipation of fumes.

Local Councils

- Promote the benefits of larger volume kitchens with large windows (and possibly balconies) to dissipate cooking fumes and improve indoor air quality.
- Create an easy-to-follow best-practice guide for homeowners to improve ventilation and air quality in kitchens.
- Provide a standard code for builders and/or homeowners for kitchen design during new construction or when retrofitting existing homes.

Fact 7

Using extraction fans and keeping doors and windows open can reduce the average in-kitchen particulate matter exposure by about 2-times compared with natural ventilation conditions through open doors alone.



Extraction fans, along with opened doors and windows, can reduce kitchen occupants' exposure to fine particles by two-fold.

Home Occupants

- Install a retrofit extraction fan or hood in the kitchen, if possible.
- Consider installing an extraction fan at the window to increase the ventilation rate.
- Keep the extraction fan on during cooking.
- Open kitchen windows and doors during and after cooking, if weather conditions permit and safety precautions are not compromised, to remove potential residual contaminants.
- Ensure that the cooking stove and oven are near a window for faster removal of cooking fumes.
- Regularly maintain cooking stoves and exhaust fans to ensure their efficient operation.

Builders & Homeowners

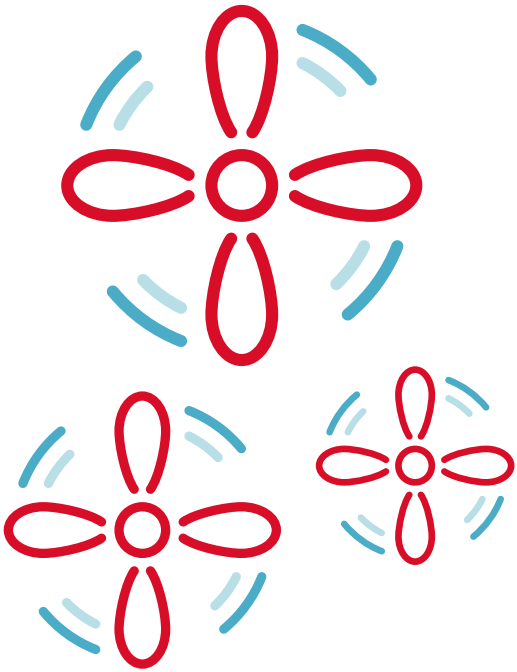
- Provide infrastructure (e.g. electricity and electrical connections) in homes for extraction fan installation in the kitchen.
- Provide double sliding doors/windows with mesh for ventilation and insect control.

Local Councils

- Provide awareness materials such as pamphlets and guides on the importance of improved ventilation conditions indoors, especially in the kitchen during cooking.
- Provide a standard code for builders and/or homeowners for kitchen design during new construction or when retrofitting existing homes.

Fact 8

Maintaining thermal comfort is crucial to the health of home occupants. Extraction fans improve thermal comfort by allowing for higher heat exchange and reducing in-kitchen humidity by 20%–40% during cooking.



Most kitchens in low- and middle-income homes exceed the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard (RH >40%, temperature >23°C) for thermal comfort. In-kitchen conditions can be improved by using extractor fans/hoods during cooking.

Home Occupants

Use extraction fans/hoods during cooking and keep windows open during cooking if the weather permits.

Builders & Homeowners

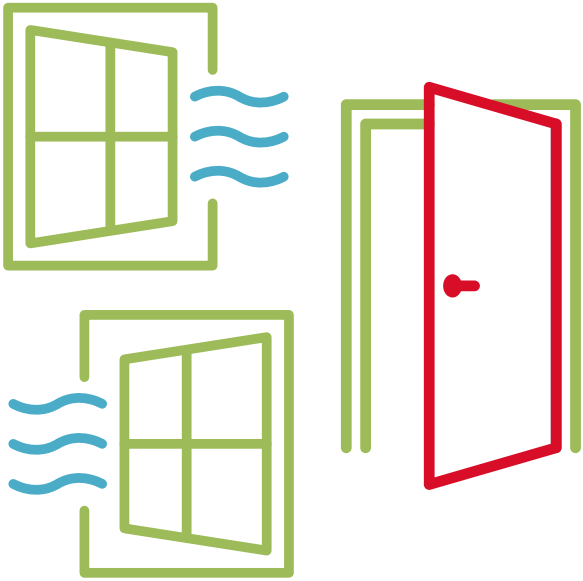
Design kitchens with high ceilings and larger windows/ balconies to allow for better thermal comfort conditions, especially in warmer/humid countries.

Local Councils

Establish local thermal comfort standards for homes to be considered in building design and to spread awareness amongst home occupants.

Fact 9

Opening kitchen windows and doors during cooking can reduce carbon dioxide levels by up to 54% more than opening the doors only.



Keep windows and doors open during cooking whenever possible to improve the ventilation and reduce the in-kitchen carbon dioxide levels.

Home Occupants

Always keep windows and doors open during cooking whenever the weather permits and when it is considered safe.

Builders & Homeowners

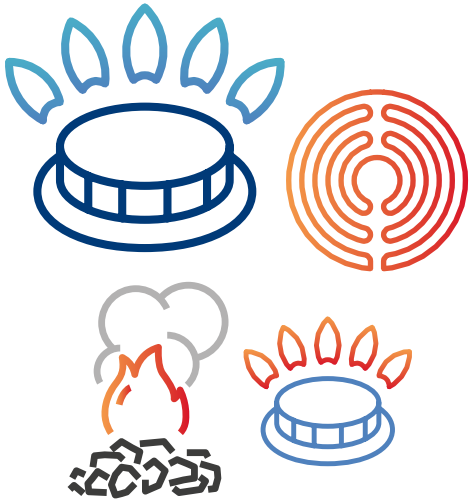
- Install mosquito screens on windows and doors to exclude flying insects in affected countries.
- Install CO_2 monitors that provide easy-to-understand green, amber, and red traffic light colour-coding to warn occupants to increase kitchen ventilation during cooking.

Local Councils

Promote the importance of natural ventilation in kitchens during cooking.

Fact 10

Reliance on multiple fuel types (clean and polluting), which is referred to as fuel stacking, for cooking can stand in the way of the adoption of clean cooking practices.



Reduce fuel stacking by encouraging a switch to cleaner cooking fuels and stoves. This can be achieved by making clean fuels and compatible cookstoves and devices accessible and affordable.

Home Occupants

- Reduce the use of polluting fuels.
- Use cookstoves compatible with clean fuels.
- Use devices such as pressure cookers to reduce cooking time.

Builders & Homeowners

- Set up supply chains for the delivery and maintenance of LPG cylinders.
- Provide infrastructure and space to accommodate the use of clean cooking fuels and devices.

Local Councils

- Make clean fuels more affordable than polluting fuels through subsidies and pro-poor tariffs and tax the use of polluting fuels.
- Consider subsidising the first few KWh of electricity supply to encourage the use of e-cookers, especially for low-income households.
- Demonstrate and provide training in the use of energy-efficient cooking devices and cooking techniques.

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