Advancing Sustainable Energy Solutions and Energy Efficiency in Buildings

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NOVEMBER 2024

doi.org/10.33548/SCIENTIA1111

EARTH & ENVIRONMENTAL SCIENCES

Scientia

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Buildings play a significant role in our global energy consumption, accounting for one-third of the total energy used worldwide. Unfortunately, they are also responsible for nearly 40% of carbon dioxide emissions generated annually. To combat climate change, address energy scarcity, and achieve net-zero carbon goals, focusing on sustainable renewable energy and energy-efficient building technologies is key. Dr Praveen Cheekatamarla of Oak Ridge National Laboratory is working with his colleagues to advance energy-efficient and decarbonisation technologies. Their work is critical in tackling these challenges and analysing innovative solutions.

Energy Demand in Buildings

Energy plays a vital role in modern society, but unfortunately, it also contributes to greenhouse gas emissions. Addressing this challenge is crucial as global energy consumption continues to rise due to economic and population growth. By 2050, different energy outlook studies predict a 50% increase in global energy demand, driven by a 65% increase in building energy consumption, a 79% increase in electrical power generation, and a 40% increase in natural gas consumption. It is particularly problematic that, conventionally, 65% of energy is lost during production and distribution. Consequently, the energy supplied to buildings must be fully optimised.

In residential buildings, heating and cooling alone account for up to 50% of total energy consumption. There is also a growing demand for energy in buildings due to improved access, affordability, economic growth, new energy consumers (e.g., to power electric vehicles), and ever-increasing building footprint. Concerted action is required to protect future generations from the impact of continued fossil fuel consumption.

Buildings also represent a significant resource with untapped potential for reducing global energy demand and minimising environmental impacts, and they are central to the transition to a lower-carbon future. A significant reduction in existing building stock's energy consumption is the first step in this transition and improving energy efficiency is vital.

Key strategies for unlocking this potential involve architectural enhancements, innovative envelope materials (e.g., enhanced insulation) and designs, effective energy management (e.g., smart energy systems), and optimised building equipment. Energy-efficient and sustainable technologies are necessary to lower energy consumption and carbon footprints, with many technologies being explored to meet the increasing energy demand in buildings.

Dr Praveen Cheekatamarla of Oak Ridge National Laboratory in the USA and his colleagues are dedicated to reducing energy consumption and carbon dioxide emissions in buildings to help mitigate climate change. They are particularly interested in the concepts of energy efficiency, renewable energy, and decarbonisation technologies in shaping a more sustainable future.

What is Needed for a Successful Transition to Sustainable Clean Energy?

In the global market, the uptake of available energy-efficient technologies remains poor, mostly impeded by cost, reliability, lack of education, firm implementation of policies, limited retrofit capability, and incentives. When choosing an energy technology, the power source must be considered in a holistic evaluation, which considers economic, social, environmental, and energy system impacts. The successful transition to sustainable clean energy should consider affordability, capacity to retrofit, and the ability to replace existing technologies without imposing financial or site burdens on consumers. Equitable participation across all consumer sectors, including underprivileged communities, is essential.

The wider adoption and integration of technologies, such as renewable energy based combined heat and power systems and heat pumps, into energy markets is needed as they are considered easily deployable and accessible yet capable of making a significant difference to primary energy consumption while improving energy resilience.

Future work could usefully consider the implications of utilising these technologies in different climatic zones.

Technological Solutions for a More Sustainable Future

On-site cogeneration, also known as 'combined heat and power', is a system that simultaneously produces heat and electricity. This option allows for the efficient use of available energy resources, including renewables, to support current and future building energy needs while still targeting grid resiliency, energy, and environmental security at an affordable cost. It is more efficient because it utilises otherwise wasted heat from electricity generation. By capturing this heat, cogeneration maximises energy yield. In this way, cogeneration technologies offer numerous benefits in meeting the growing energy demand while lowering the environmental impact.

Dr Cheekatamarla and his colleagues have investigated the impact of cogeneration systems on residential buildings, focusing on optimising system capacity, efficiency, and achieving an enhanced energy balance, reduced carbon footprint, and improved resiliency. Their work highlights that current cogeneration technologies can significantly reduce greenhouse gas emissions while enhancing grid resiliency, flexibility, and sustainability. Hybridising cogeneration with on-site renewable energy and low-carbon fuels, such as biogas and hydrogen, further decreases the building's carbon footprint. However, the benefits of cogeneration depend on the carbon intensity of the electrical grid. If the grid is already low-carbon and resilient, the advantages may be limited.

Dr Cheekatamarla and his team's research contribute to a more sustainable future by optimising cogeneration systems and addressing the evolving energy landscape.

Additionally, researchers have explored generating electricity directly from the heat produced during fuel combustion. While these technologies can potentially improve energy efficiency, the choice of fuel source significantly impacts overall carbon emissions reduction.

Balancing Resilience and Decarbonisation in the Energy Transition

The energy transition faces a critical challenge in balancing resilience, ensuring reliable energy supply with decarbonisation. To transform the electric grid with intermittent renewables, we need complementary technologies like energy storage, on-site polygeneration – where multiple forms of energy, such as heating and cooling, are produced, right where they will be used – and flexible grid-interactive solutions, for electric vehicles for instance, to support both the vehicle's charging needs and the grid's stability and efficiency.

While wind and solar production has increased significantly, reducing reliance on fossil fuels via energy efficiency remains a crucial strategy. Buildings can actively contribute by becoming prosumers, meaning they generate their own energy and feed it back into the grid. This integration enhances grid stability and allows for intermittent renewable energy sources. Buildings must adopt energy-efficient technologies and eliminate on-site fossil fuel consumption. As technologies develop, using renewable fuels, such as biogas, hydrogen, and methane, is essential, as these resources help meet current demands while minimising greenhouse gas emissions until we achieve 100% renewable, carbon-free energy production for buildings.

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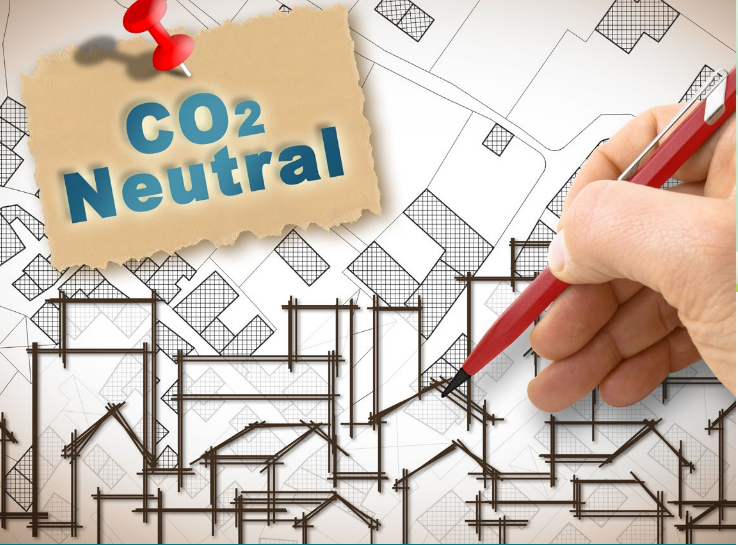

The significance of energy storage is also rapidly growing. Renewables (such as wind and solar) are intermittent, and the ability to store this energy, for example, in batteries, to be used during peak demand is critical to ensure energy security, energy resiliency, energy efficiency, and grid stability.

New Insights into Cleaner Energy and Carbon Capture Technology

Previous research in this field has not explored how the carbon dioxide intensity of the grid affects the overall carbon footprint of various energy technologies. Dr Cheekatamarla's work addresses this knowledge gap by providing an overview of how grid emissions impact a specific thermal technology's carbon footprint. Existing literature also lacked a comprehensive comparative analysis of conventional, emerging and new thermal energy technologies used in buildings. His research also seeks to fill this gap by comparing different building thermal technologies. He has also explored other building technologies, including materials, appliances, and integration concepts, which significantly lower the overall energy consumption in both new and existing buildings.

Dr Cheekatamarla and his colleagues have shown that we can improve energy efficiency, enhance resiliency, and reduce carbon dioxide emissions by promoting cleaner energy sources and carbon capture technology. Exploring additional power sources like fuel cells, thermionic emitters, and thermo-photovoltaics (a process that transforms heat into electricity) will deepen our understanding of cogeneration technologies and their applications. Most importantly, heat pumps have also been shown to effectively reduce the carbon footprint associated with heating and cooling, serving as energy-efficient alternatives to fossil fuel heating systems. Alongside this, hydrogen-fuelled solid oxide fuel cells, known as SOFCs (devices which convert hydrogen or hydrogen containing fuels into electrical power), have also demonstrated efficiency and reduced carbon footprint. Cogeneration systems can also compete with and complement heat pump systems, particularly in areas with carbon-intensive electricity generation.

Building a Brighter and More Sustainable Future

Dr Cheekatamarla has contributed to a better understanding of global trends and strategies for building decarbonisation. His work emphasises a systemic value framework and highlights the need for sustainable practices and innovative solutions to achieve energy efficiency and reduce greenhouse gas emissions in buildings. His research aims to create more sustainable and resilient buildings by integrating advanced technologies and optimising energy systems. His research supports the view that in pursuing sustainable energy solutions, it is imperative to weigh the immediate carbon footprint and the long-term implications of primary energy sources. When choosing technologies for electricity and thermal energy needs in buildings, factors like cost, resiliency, and capacity/availability, must be considered alongside their environmental impact.

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MEET THE RESEARCHER

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In 2004, Dr Praveen Cheekatamarla obtained his PhD in Chemical Engineering at the University of Alabama. He has over 20 years of experience in the dynamic and ever-evolving energy industry, accompanied by more than 120 scientific publications and presentations. From 2009 to 2019, he held various positions at Atrex Energy, including serving as Director of Research and Product Development. Since 2019, Dr Cheekatamarla has been a senior member of the research and development staff at Oak Ridge National Laboratory. This organisation strives to empower leaders and teams to pursue breakthroughs in an environment marked by operational excellence and engagement with local communities. By delivering scientific discoveries and technical breakthroughs, Oak Ridge National Laboratory aims to ensure energy security for the USA.

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FUNDING

U.S. Department of Energy, Southern California Gas, Watt Fuel Cell, Spark Thermionics, Utility Global

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