Wrap Up **Warm**

How can we achieve the heat transition?

Germany aims to achieve climate neutrality by 2045. This means that greenhouse gas emissions must be reduced by over 88% compared to 1990 levels, with remaining emissions fully balanced by natural carbon sinks, such as forests, soils and seas. The country also aims to become carbon negative from 2050 onwards, meaning that the sum of emitted greenhouse gases must be lower than the absorption of these emissions by natural sinks. Germany's federal government has established these targets in the Federal Climate Change Act, the Bundesklimaschutzgesetz.

But how can this be achieved for buildings and cities? We spoke with TUM scientists who are researching strategies and technologies for the heat transition. While this article primarily casts light on the situation in Germany, these issues affect every country that aspires to achieve climate-neutral heating and energy supplies.

All texts by Gitta Rohling

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung

Warm anziehen

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Ein warmes Zuhause gehört zu unseren Grundbedürfnissen. Wegen der steigenden globalen Temperaturen und der Notwendigkeit, den CO_2-Ausstoß zu reduzieren, muss sich allerdings die Art ändern, wie wir Wärme erzeugen und nutzen. Deswegen haben viele Länder die Ära der Wärmewende eingeläutet. Es ist ein komplexer Prozess, der viel technisches Wissen und eine komplette Transformation der Systeme und Energienetze erfordert. Erneuerbare Energiequellen wie Photovoltaik und Geothermie spielen eine wichtige Rolle, um einen bedeutend höheren Anteil unserer Strom- und Wärmeversorgung daraus zu beziehen. Zudem sollten wir einen ganzheitlichen Blick auf Gebäude, Quartiere und Städte werfen und uns auf die Kriterien fokussieren, nach denen wir Technologien sinnvoll auswählen. Wissenschaftler der TUM forschen an Strategien und Technologien, wie die Wärmewende gelingen kann – vom einzelnen Gebäude über die Zusammenarbeit mit Kommunen und den Ausbau von Geothermie bis zum Einsatz digitaler Lösungen. □

A warm, comfortable home is a basic human need. However, we need to change the way in which we generate and use heat. Rising global temperatures and the need to reduce our carbon emissions have ushered in a new age for energy supplies: the age of the heat transition. Following the established concept of the energy transition, which aims to effect a fundamental change in how we generate energy, the heat transition focuses on the urgent need to make our heating systems and heat generation processes greener and more sustainable.

The challenges we face are tremendous. At present, fossil fuels like oil and gas still account for the major share of heat generation. Not only are these resources finite, but burning them also emits vast amounts of greenhouse gases into the atmosphere. This contributes significantly to climate change and threatens the very foundations of life for future generations.

Yet, while the challenges ahead are certainly daunting, there is also good news. "We have the technical capabilities to make buildings climate neutral," says Prof. Werner Lang, who holds the Chair of Energy Efficient and Sustainable Design and Building at TUM and is also Vice President for Sustainable Transformation. "We just need to use them," agrees his colleague Thomas Hamacher, Professor of Renewable and Sustainable Energy Systems.

Many roads lead into the warmth

When it comes to the energy transition, there are two main levers we can pull. First, we need to reduce heat losses and energy demand by renovating buildings. Second, we need to restructure our electricity and heat supplies to rely more heavily on renewable energy sources.

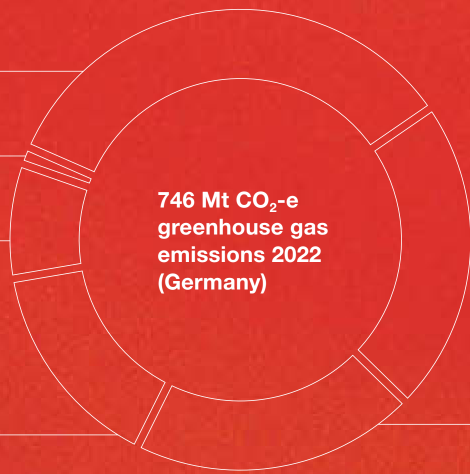
Digitalization also has an important role to play. "It enables us to significantly optimize or adjust our energy consumption more effectively to our actual needs," says Christian Hepf, who is currently writing his doctoral dissertation at TUM's Chair of Building Technology and Climate Responsive Design.

Far-sighted heating

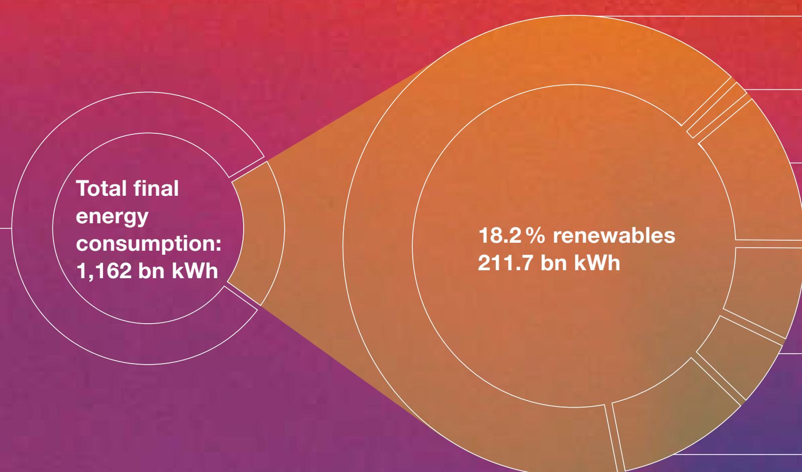
Above all, we need to take a more holistic view of buildings, districts and cities rather than discussing individual technologies in isolation. "It's extremely important that we consider the entire life cycle of a building," emphasizes Lang. Simply looking at the renovation costs is not enough. "The decisive question is this: How high will the operating costs be in the decades ahead if we continue to rely on fossil fuels rather than renewable energy? The difference in operating costs is far higher than the investment involved." Hamacher adds that, when it comes to city and municipal authorities, "we need to consider the entire region with regard to potential for the heat supply system. We should spend less time discussing individual technologies and instead focus on the criteria we use to select appropriate technologies.

So, will we achieve the heat transition? "The answer to this question seems obvious to begin with because we could argue that, above all, it's a question of attitude," says Hepf. As the maxim goes, where there's a will, there's a way. Technologies drawing on different renewable energy sources already exist. And, as demand grows, these technologies will develop to become increasingly efficient and effective. "From another perspective, looking at the practicalities, this is a highly complex process that requires extensive technical expertise and a complete transformation of systems and energy grids," explains Hepf. This means that, in addition to making greater use of renewable energy sources, we must also consider a range of other aspects, from energy storage and grid expansion to political and social aspects like subsidy programs and civic initiatives. All four TUM experts believe that the problem lies less in feasibility and more in our willingness to implement all aspects of this complex process. So, until this willingness becomes more widespread, there's only one thing for it: wrap up warm. ■

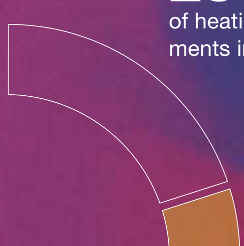
More about sustainability at TUM:
www.tum.de/en/about-tum/goals-and-values/sustainability



Shares of renewable energy sources in the heating sector (Germany, 2022)

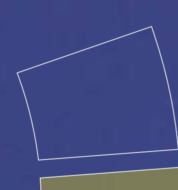


Deep geothermal energy can cover over **25 %** of heating requirements in Germany



It currently accounts for **5 %**

Achieving the targets in the European Green Deal will require us to renovate **4 %** of all buildings per year



The current rate is just **0.8 %** per year

Graphics: ediundsepp (sources: UBA 2023: Treibhausgasemissionen in Deutschland; UBA 2023: Erneuerbare Energien in Zahlen; Beer et al., DIW aktuell, 87, 6 S., 2023; Bracke & Huenges, 2022, Roadmap Tiefe Geothermie für Deutschland)

1 | Heat up Together

How municipalities can spearhead the heat transition

Putting questions to Thomas Hamacher, Professor of Renewable and Sustainable Energy Systems

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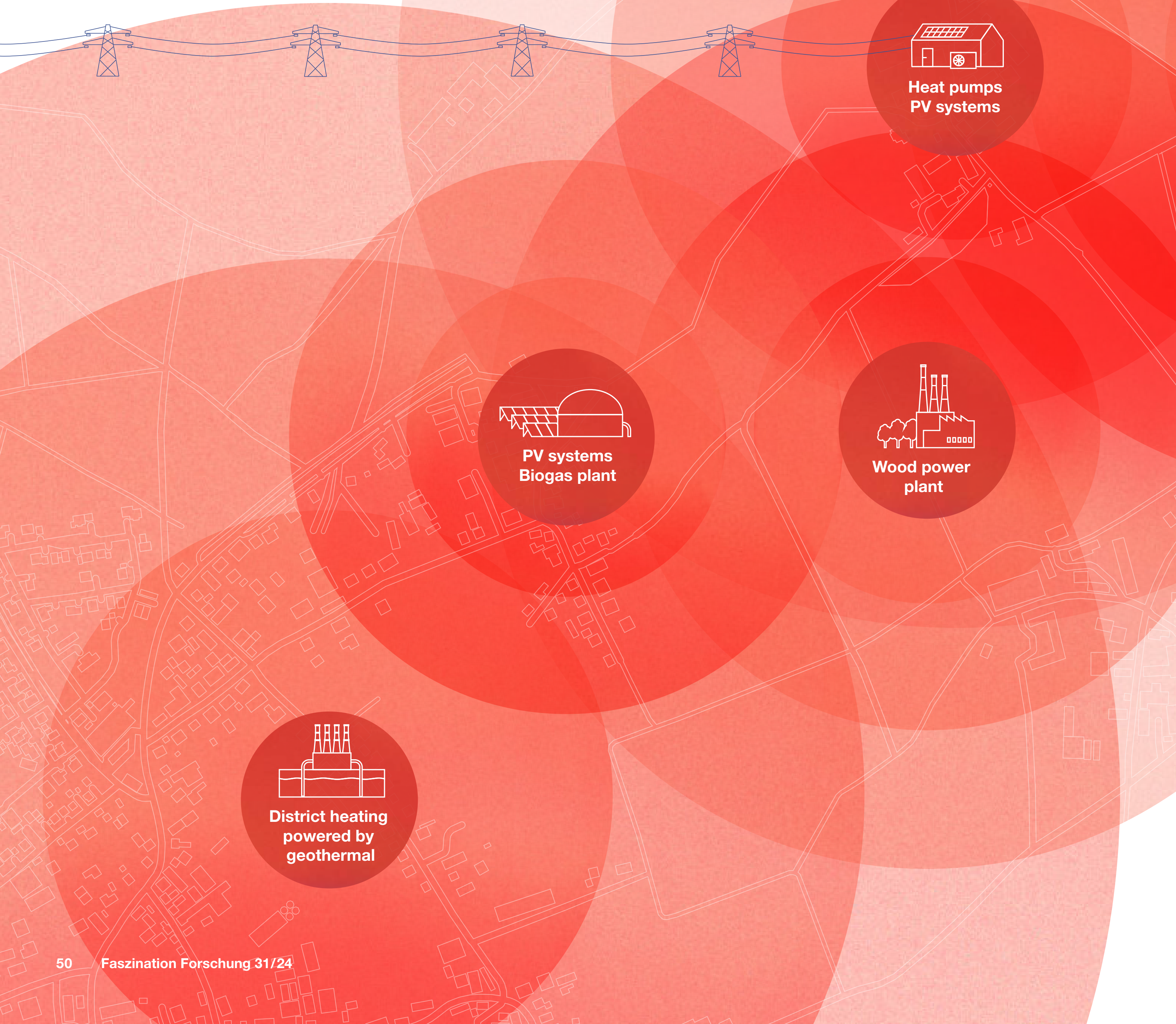
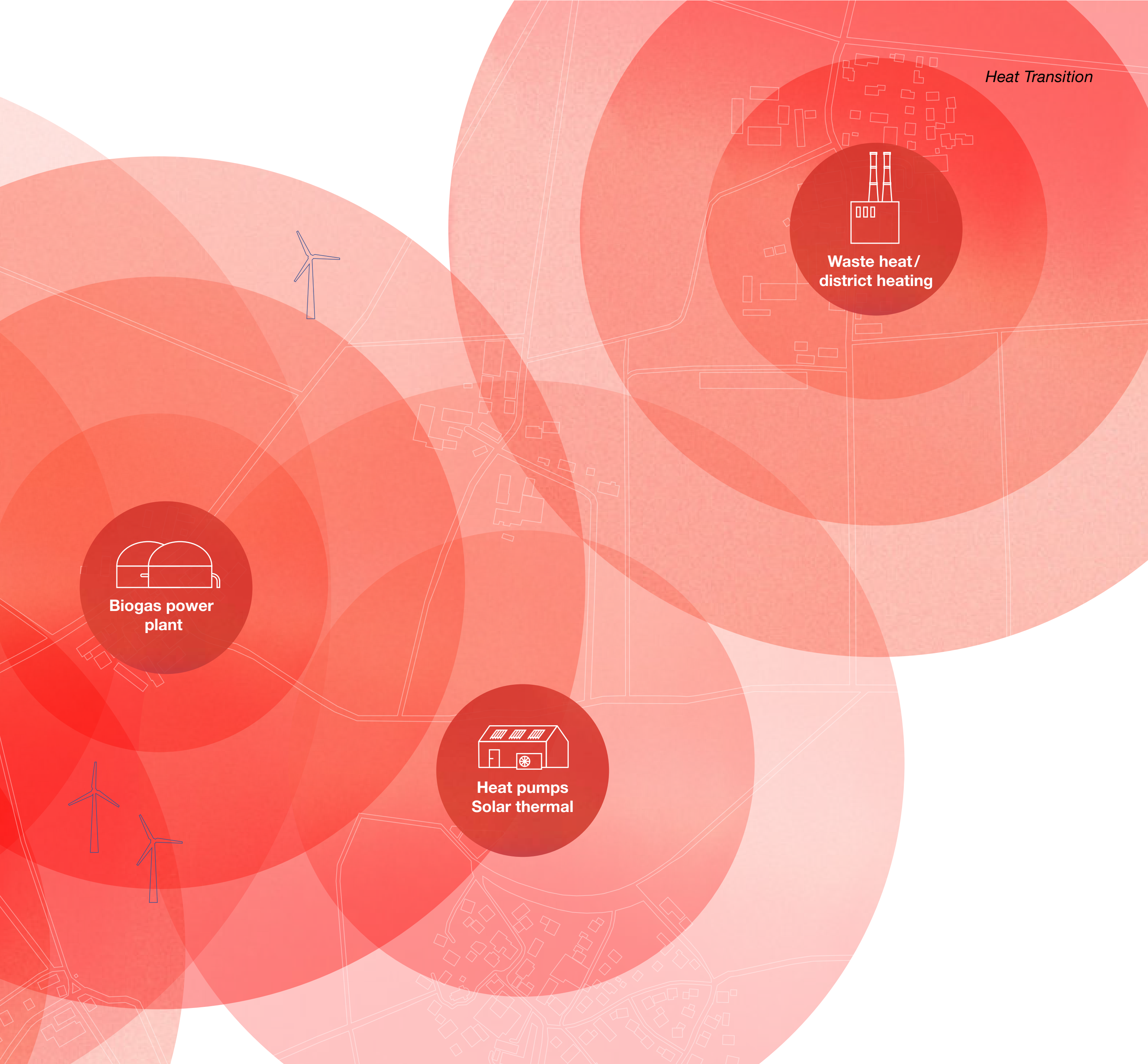
www.epe.ed.tum.de/en/ens/homepage



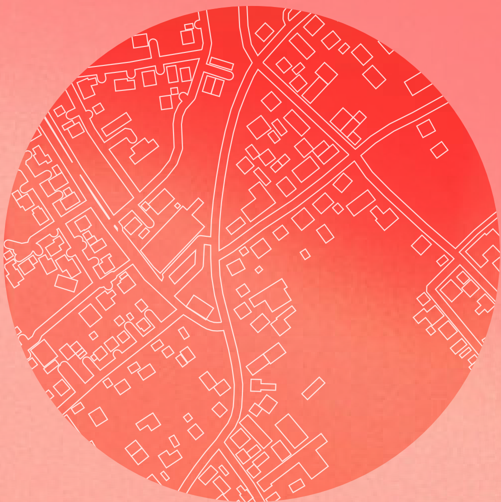


Graphics: ediundsepp

Prof. Hamacher, how can local authorities achieve a successful heat transition?

There are various technologies that have been discussed for years on end but are often not considered in strategic terms. For a while, people focused on solar thermal; this was followed by the Passive House and Zero-Energy Building concepts; today, it's heat pumps. Added to this is a cacophony of initiatives, some promoted by the state, which each have a different focus. What's missing from all of this, however, is a holistic view of energy and heat, a reasoned consideration of different measures. We should spend less time discussing individual technologies and instead focus on the criteria we use to select which technologies are suitable. A few questions are decisive for this: What does the heat supply system in a given region look like? Is there potential to use renewable energy sources? Would this region be suitable for geothermal or biomass? Where would district heating be worthwhile?

We explored these questions, for example, in the STROM research project, in which we identified heat supply areas for Bavaria and selected cities. It is about the integrated planning of the heat and energy supply and the question of how the additional electricity required for heat is delivered to consumers. Could our power grids cope with it? Or would we have to expand them? ▷



Exemplary decision criteria for technology selection:

- ? Which heat sources would be available?
- ? Could a district heating network be realized?
- ? Where are heat pumps a sensible solution?

If heat pumps are used:

- ? How will electricity consumption (incl. electromobility) develop?
- ? What contribution can PV roof systems deliver?
- ? Does the power grid need to be expanded?

What did you find out?
We need to expand local networks as well as the higher-level distribution grids. However, this always depends on the location. A place where there are many heat pumps at work will require more electricity than an area with district heating, so the distribution network will have to be expanded accordingly. In addition, energy management systems in buildings can make a significant contribution, limiting the maximum power drawn down from the power grid. These systems optimize aspects such as the interaction between a photovoltaic installation, an electric car and a heat pump, choosing the optimal time to feed power into the grid. We don't need sophisticated smart grids and we don't have to wait – we can start to expand power grids now.

But, as the owner of a house or an apartment, don't I need to wait for my local authority to do its homework before I make a decision?
Yes. The extent to which renovations make sense always depends on the supply side situation. Simply put, if a good renewable heating source is available, there is less need for renovation. Otherwise, extensive renovation is required first and the remaining heat demand has to be covered at greater expense. The responsibility for ensuring an effective link between the supply side and renovations lies with local authorities and their heat planning teams. However, we're already able to figure out very quickly which municipalities would benefit from district heating. This means we can lay the foundations for the heat transition without great effort or expenditure.

How do you support this as a researcher?
I see our role as providing the data and tools that municipal heat planning teams can rely on. That brings us to the topic of digitalization. There is a great deal of data about buildings – but we need to put it into formats that allow us to make up-to-date data available at any time. That is why we just launched the NEED research project, which aims to develop a platform that provides all the necessary data in the right form. At TUM, for instance, we're working with the local authorities in Garching to develop models for long-term heat planning, which will benefit local communities and our campus. ■

2 | Heat from **the Deep**

How we can utilize geothermal energy

Bavaria is in an enviable position: its sits on top of the Molasse basin. Located between the Danube and the Alps, this geological formation offers favorable conditions for geothermal energy projects. At depths of up to 3,000 meters, one finds water hot enough to fulfill the conditions – at least 100 to 120°C – for cost-effective electricity generation and heat supply.

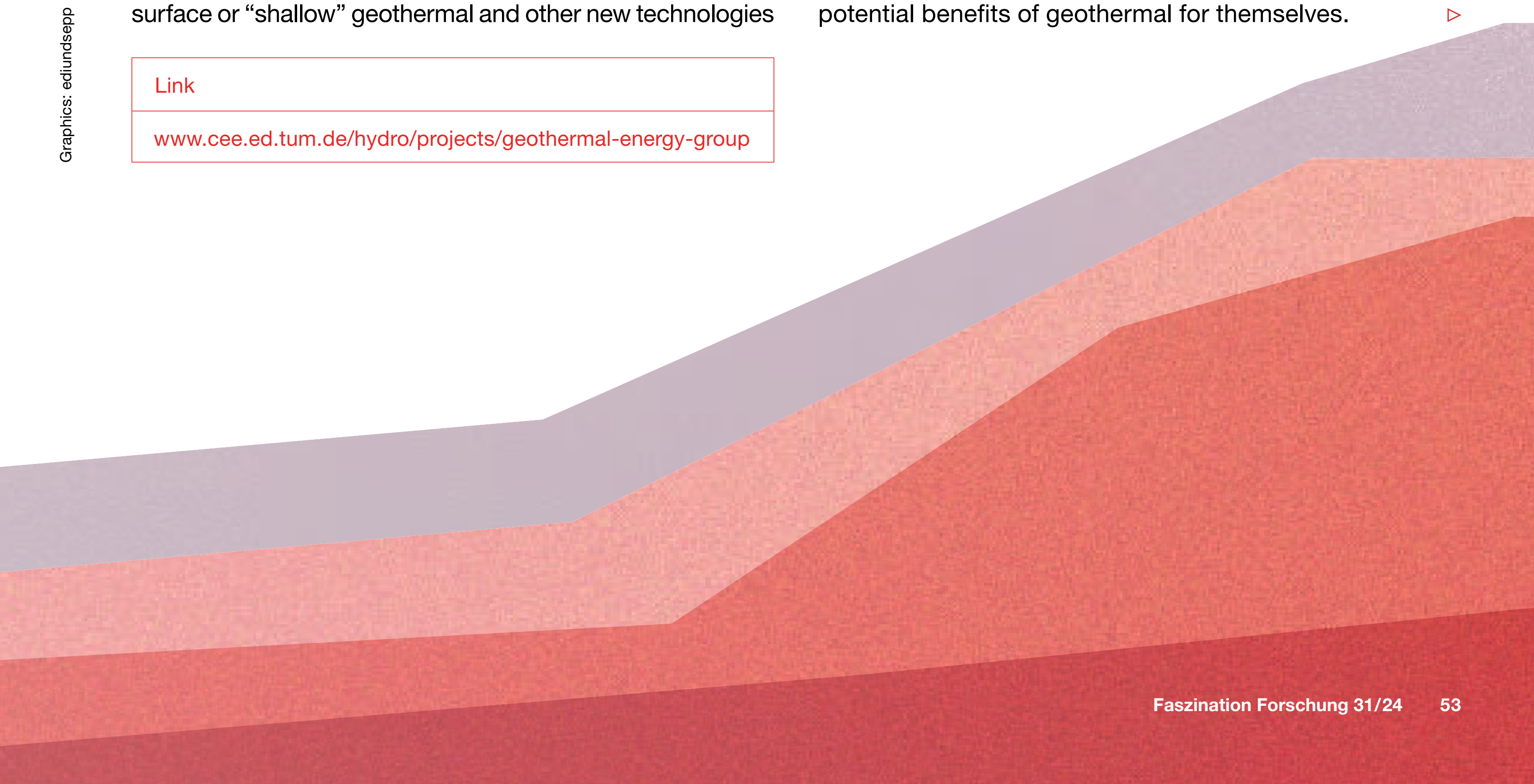
However, this isn't unique to Bavaria. Similar natural resources with vast quantities of water are widespread across Germany. "We could cover a quarter of our heating requirements with deep geothermal," says Dr. Kai Zosseder, a researcher at the Chair of Hydrogeology. Taking near-surface or "shallow" geothermal and other new technologies into account could boost this figure further. At present, however, geothermal accounts for a less than a 5% share and Zosseder is working to increase this.

Link
www.cee.ed.tum.de/hydro/projects/geothermal-energy-group

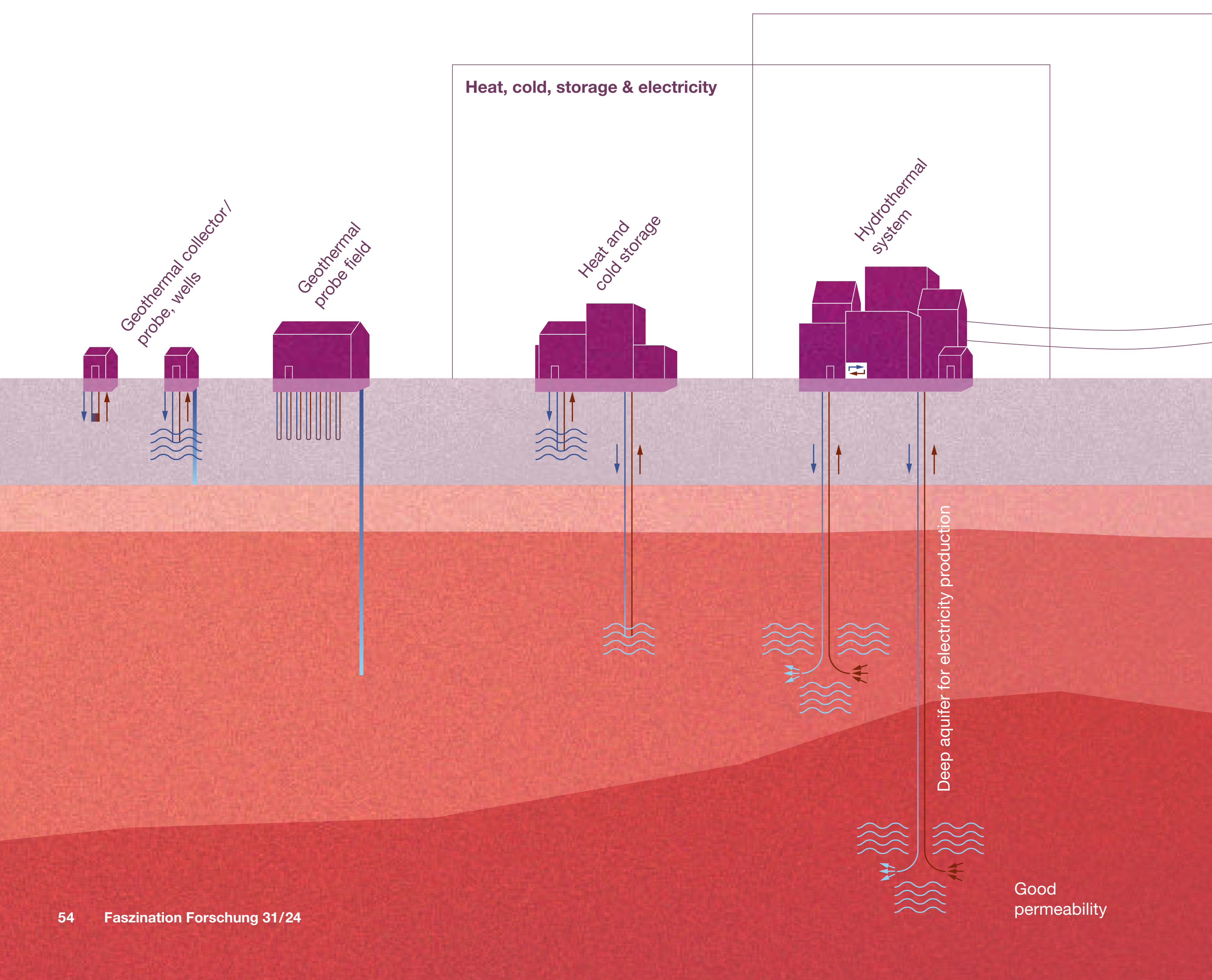
Platform promoting the exchange of data and knowledge between science, industry and politics

The Geothermal Alliance Bavaria (GAB) project, in which TUM collaborates with four other Bavarian universities, is part of this effort. It aims to advance geothermal energy systems, develop durable heating infrastructure, and thus build a bridge connecting research and practice. Zosseder primarily helps local authorities analyze and quantify the potential benefits of geothermal for themselves. ▷

Graphics: ediundsepp



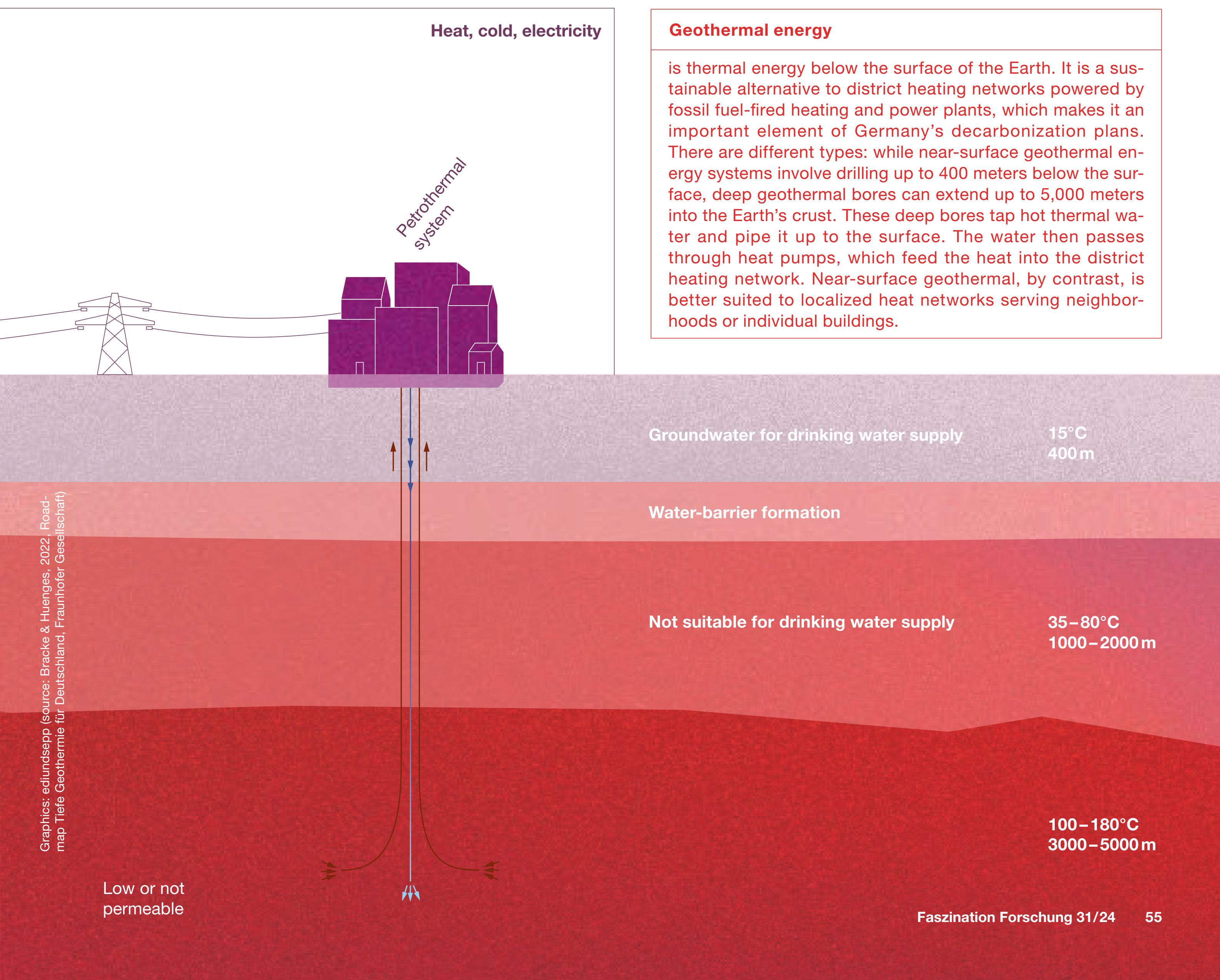
He and his team analyze data on underground conditions using bores, measurements and existing geothermal systems. They then develop methods and models to determine the spatial distribution of the potential along with new monitoring methods to ensure that these renewable resources are used sustainably. Zosseder and his team frequently receive inquiries from local authorities, especially since the German federal government introduced the Building Energy Act. “There are a few questions we focus on: Which areas would be suitable for geothermal? How should the systems be configured? But also: How can we improve the durability of the pumps, which are subject to harsh conditions with high pressures and high temperatures? In most cases, the pumps come from the oil and gas industry and have to be adapted for use in geothermal systems,” explains Zosseder.



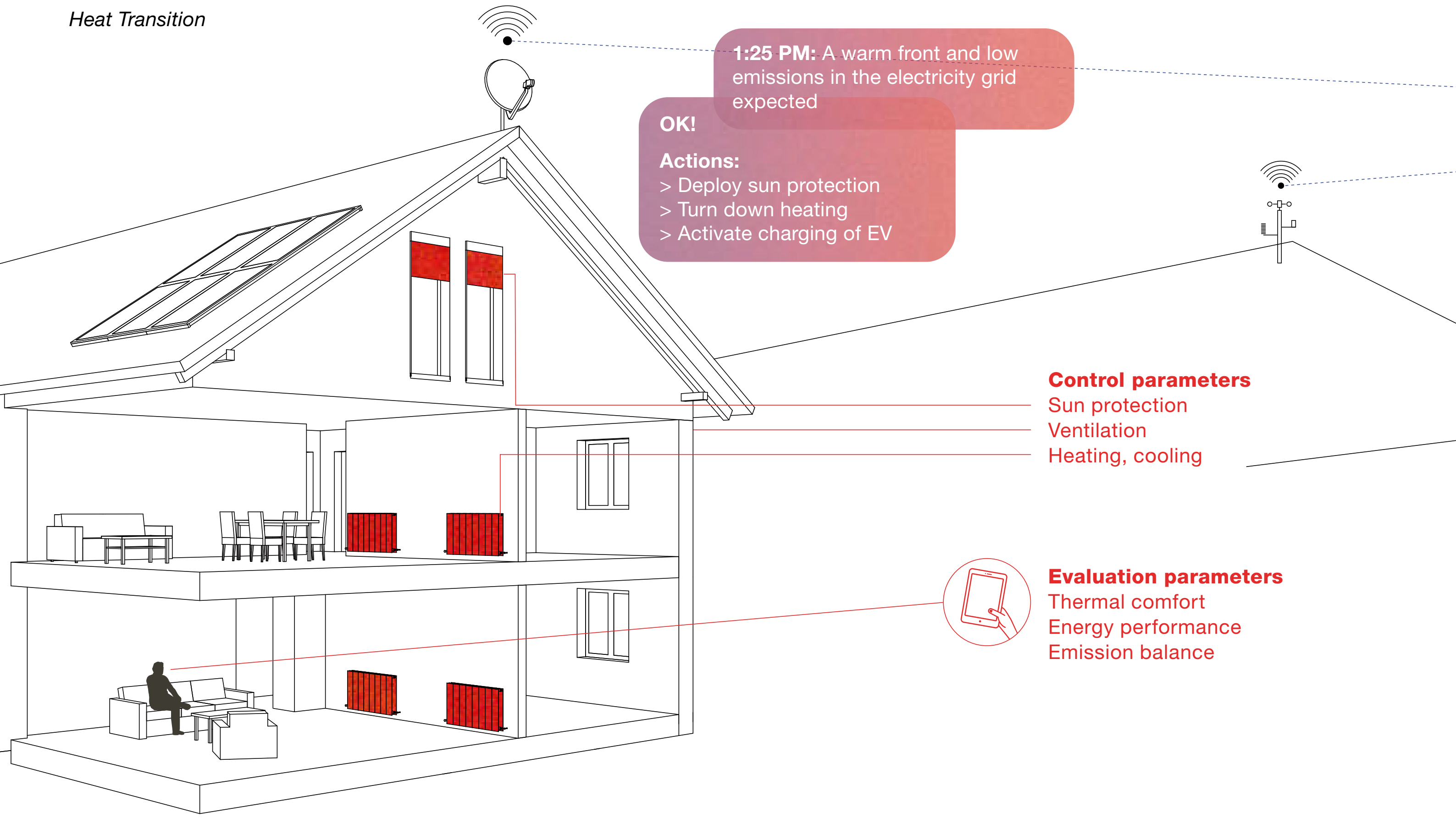
Zosseder applies his expertise to support individual local authorities. Above all, he strives to create associations that connect local authorities and make it possible to realize geothermal systems at scale. Pipelines can then send the heat where it is needed. He also conducts research into new technological developments, such as petrothermal geothermal energy systems, which is when no water is present but hot rock is available and potentially exploitable 2,000 to 6,000 meters below the ground. In truth, it is not just Bavaria and Germany, but Europe as a whole that is well positioned on geothermal. "A lot of countries have potential on this – such as Italy, where there are regions with active volcanoes," adds Zosseder. In addition to the Geothermal Alliance Bavaria, Zosseder is also involved in a range of EU research projects striving to tap the full potential of geothermal energy across Europe. ■

Geothermal energy

is thermal energy below the surface of the Earth. It is a sustainable alternative to district heating networks powered by fossil fuel-fired heating and power plants, which makes it an important element of Germany's decarbonization plans. There are different types: while near-surface geothermal energy systems involve drilling up to 400 meters below the surface, deep geothermal bores can extend up to 5,000 meters into the Earth's crust. These deep bores tap hot thermal water and pipe it up to the surface. The water then passes through heat pumps, which feed the heat into the district heating network. Near-surface geothermal, by contrast, is better suited to localized heat networks serving neighborhoods or individual buildings.



Graphics: ediundsepp (source: Bracke & Huenges, 2022, Roadmap Tiefe Geothermie für Deutschland, Fraunhofer Gesellschaft)



3

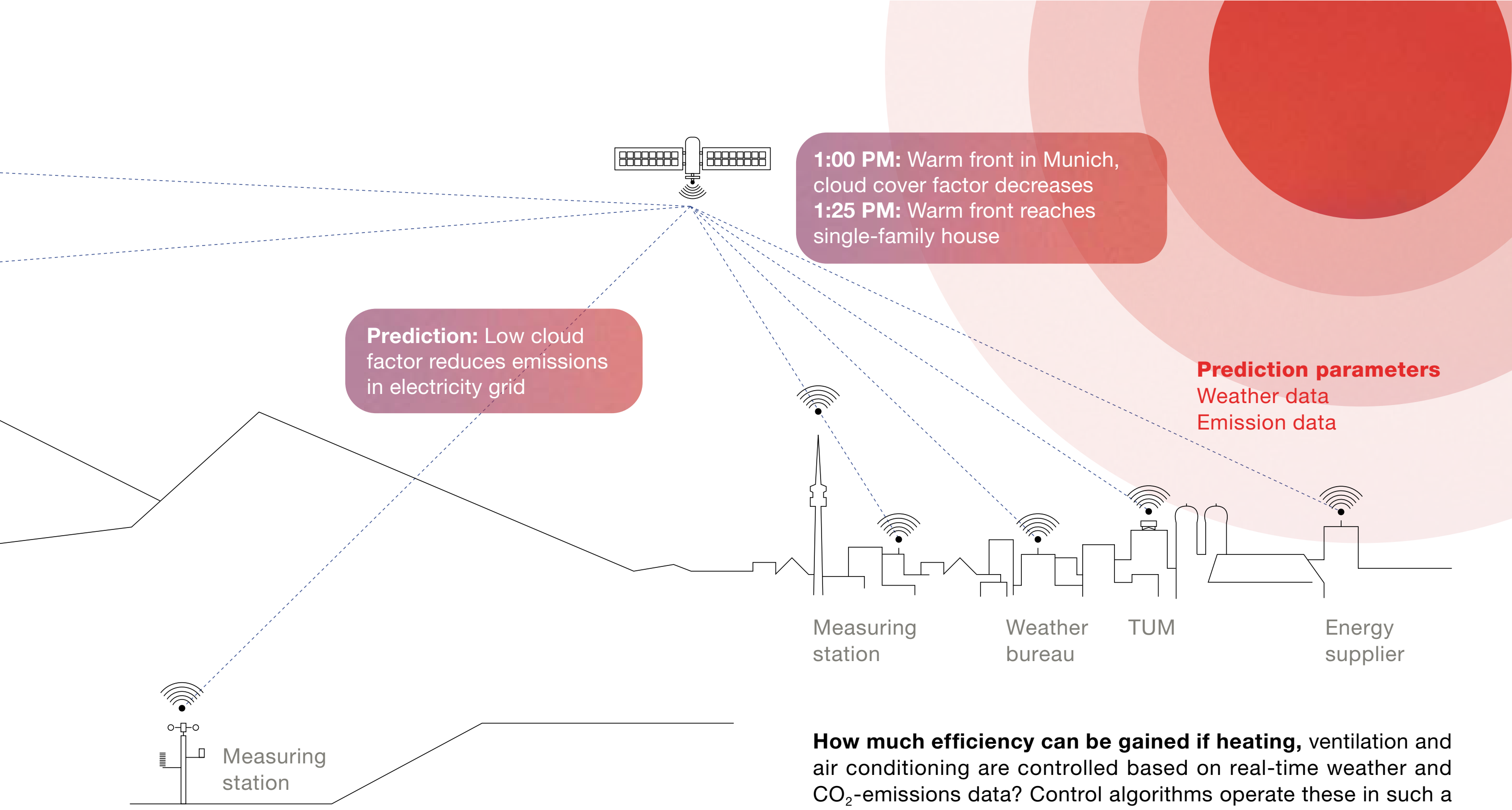
Let the **Sunshine In**

How to make effective use of weather forecasts

Three questions for Christian Hepf, doctoral student at the Chair of Building Technology and Climate Responsive Design

Mr. Hepf, what role will digitalization play in the heat transition?
Digitalization makes it possible to tailor energy consumption in buildings and cities more effectively to actual needs, ideally with reductions in greenhouse emissions as the definitive control parameters and not financial savings. Real-time measurement and sensor data about energy and heat consumption, and the ability to forecast future consumption, open up enormous potential to optimize the efficiency of the heat and power network. Over the long term, this could lead to greater energy flexibility and, as a result, improved grid stability. Consumers can also use intelligent energy management systems to reduce their energy consumption and thereby cut their costs and CO_2 emissions.

Link
www.arc.ed.tum.de/en/klima/start



How much efficiency can be gained if heating, ventilation and air conditioning are controlled based on real-time weather and CO_2-emissions data? Control algorithms operate these in such a way that thermal comfort, energy consumption and CO_2 emissions are optimized.

Graphics: ediundsepp (source: TUM)

You are currently writing a dissertation analyzing how weather and CO_2 data can be used to make a meaningful contribution to the heat transition. Could you tell us about it?
To be precise, my dissertation is about enabling building technology to operate more efficiently. The aim is to use control algorithms to optimize how these systems operate so that buildings consume as little energy as possible and generate as little CO_2 emissions as possible, all without compromising thermal comfort. I take advantage of current and future data about the weather and about CO_2 emissions from Germany's power grid. In the beginning, I tested the whole thing in the solar station, a measurement room on the roof of TUM's main building, at an altitude of almost 30 meters.
Drawing on this data, I test various scenarios in a thermodynamic simulation. So, for example, the heating system powers down when it knows – thanks to the forecast data – that the sun will come out soon. I can also operate electrical devices, like a heat pump, in phases when the emissions from the electricity grid are particularly low because renewable energy sources account for a high proportion of total generation. The simulation allows me to test the control algorithm under different conditions. This means, for example, that I can change the location of a proposed building and evaluate how its control system would behave in a different climate or in combination with a different electricity grid.

What insights have you gained?
I'm still in the final stages of my dissertation, so although I can't verify everything with 100 % certainty, I've been able to identify certain tendencies. One thing that has become clear is that a building's thermal mass has a significant influence on whether intelligent control systems are successful. So, the greater a building's thermal mass, the longer it takes to respond to temperature fluctuations, which results in greater energy savings and CO_2 reductions. We can see that this works better for cooling-related energy needs than for heating. And, fundamentally, I've determined that we can save a lot of CO_2 through distributed energy generation, such as using photovoltaics or solar thermal systems, as this eliminates the energy losses incurred during transport. ■

4

That's on **the House**

How to heat buildings in a climate-neutral way

Research at the Institute of Energy Efficient and Sustainable Design

Link
www.cee.ed.tum.de/en/enpb/home

Do you dream of a house that produces more energy than it consumes? Almost ten years ago, Prof. Werner Lang and his team designed the energy concept for a house that does exactly that and built it in Hallbergmoos, a town north of Munich, with the help of a dedicated contractor. Its walls, floors and roof correspond to ambitious Effizienzhaus standards. Its photovoltaic system provides electricity and hot water – more than the building needs, in fact. The surplus electricity is either used for the EV charging point or fed into the power grid. "The important insight for us was that it is possible to build an energy-plus building. In fact, it is relatively simple. It wasn't particularly complicated or expensive to build," says Lang. The pioneering achievement of this project lay in producing the evidence, which was achieved by measuring the building's energy and heat consumption over a two-year period.

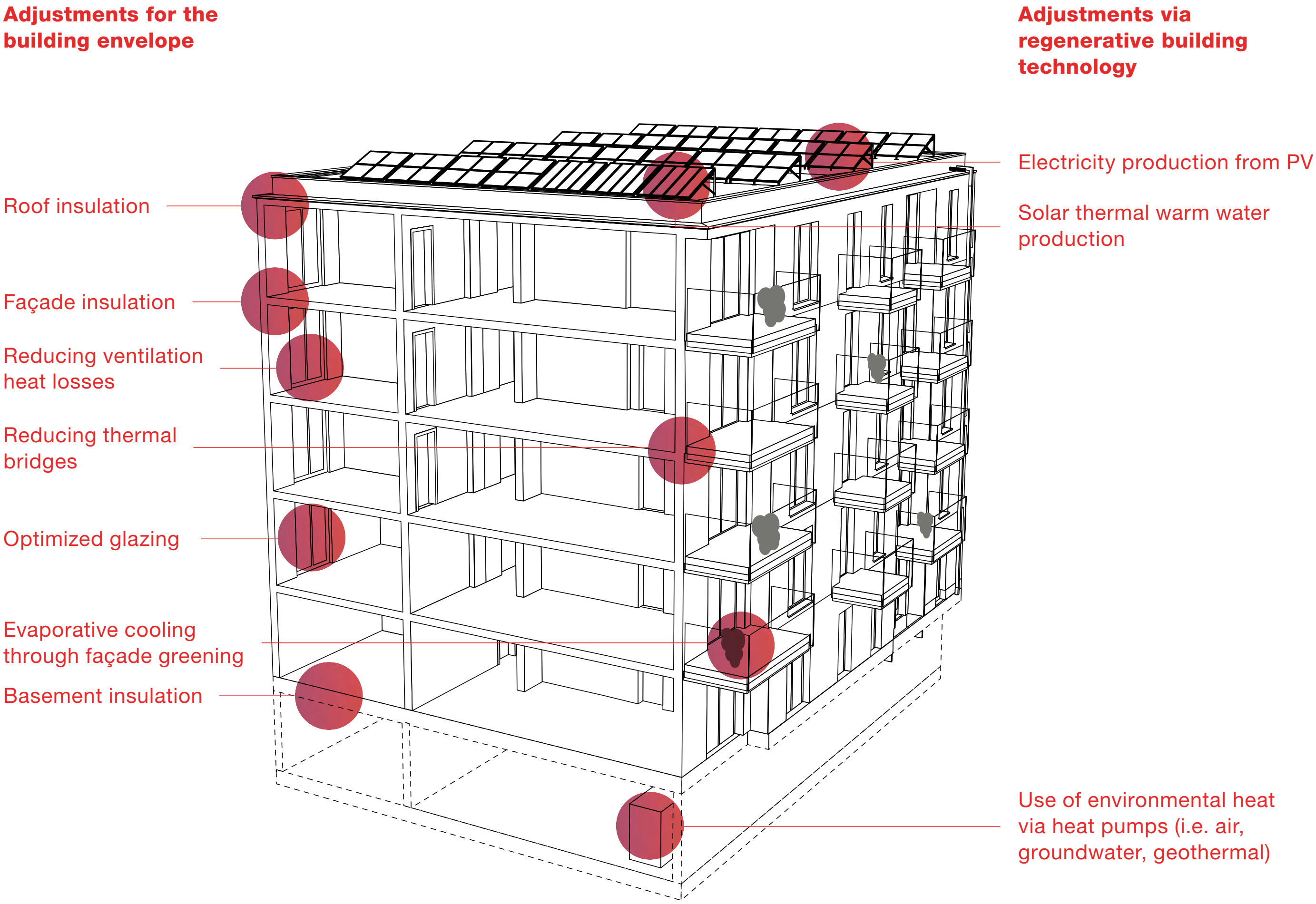
The Effizienzhaus

The Effizienzhaus (Efficiency House) standard provides a benchmark to guide the design and construction of energy-saving buildings in Germany. It indicates how energy-efficient a building is in comparison to a reference building. For example, an Efficiency House 40 only requires 40% of the primary energy used compared to a reference building defined in the German Building Energy Act.

At the Solar Decathlon, an international collegiate challenge, students went even further than the energy-plus house in Hallbergmoos. They created an energy-plus house with an outstanding energy concept, building it almost exclusively out of sustainable materials and even implementing an efficient water treatment system. They also had a further challenge to overcome: with the house built in a hot Texan environment, it needs to be both heated and cooled efficiently. This is ensured by a heat pump that, in effect, works in reverse when appropriate. So, rather than removing heat from the air outside to heat the interior, it extracts heat from the interior and emits it outside.

What about an old house?

The building sector accounts for about 37% of Germany's final energy consumption – 32% for heat in buildings and 5% for heating water. Three quarters of building-related emissions are generated through operation, with the rest caused by gray energy. This is the energy consumed in the building's construction as well as in manufacturing, transporting, installing and disposing of all the heating, ventilation and air-conditioning systems, sanitary systems, electrical systems, lighting systems and security technology.



The main challenge is existing buildings. "A total of 65% of today's buildings were built before 1977, before the first legislation on heat insulation came into effect," says Lang. Until then, Germany had no public regulations on the use of energy-saving heat insulation in buildings. A typical detached house built in the 1970s without further refurbishment uses around 250 kWh per square meter of heating energy per year. For context, the standard for low-energy buildings sets a maximum limit of 25 kWh per square meter per year.

Let's get to it!

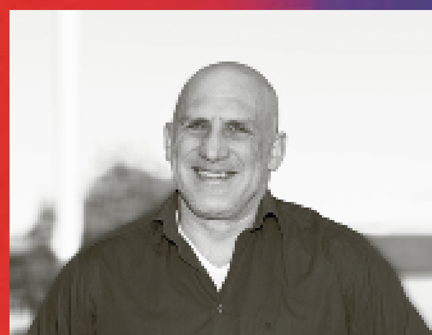
So, how can we change this? According to Lang, there are two main, interconnected levers we can pull. "First, we can drastically reduce heat losses – and, therefore, our energy needs – by carrying out renovations, such as installing façade insulation, roof insulation and triple-glazed windows. Second, we need to source significantly more power and heat from renewable energy, such as through photovoltaics and geothermal." Lang and his team have demonstrated the positive impacts of such measures for new buildings in the BEWOOpt research project. The researchers examined how to make environmentally and economically optimized homes a reality. An environmentally sound building envelope and the use of photovoltaics makes it possible to reduce greenhouse gas emissions by more than 70% across a 50-year lifespan compared to a reference building.

In the European Green Deal, Europe has set itself the target of reducing its carbon emissions to zero by 2050, thereby becoming the first climate-neutral continent. If Germany is to reach this target, it will have to renovate buildings at a rate of 4% per year. At present, the renovation rate is just 0.8% per year.

"We can get down to business," says Lang. "For new buildings, the KfW 40 standard has become common practice. It's future-proof – and we can achieve it for existing buildings, too." ■

Prof. Thomas Hamacher

is Professor of Renewable and Sustainable Energy Systems. He previously worked at the Max Planck Institute for Plasma Physics, most recently as Head of the Energy and System Studies Group.



Dr. Kai Zosseder

conducts research at the TUM Chair of Hydrogeology. He was previously a research assistant and risk analyst at the German Aerospace Center (DLR) and the Bavarian State Office for the Environment (LfU).

Christian Hepf

Since completing his Master's degree, Christian Hepf has conducted research as a doctoral student and Deputy Director of the Chair of Building Technology and Climate Responsive Design, currently held by Prof. Thomas Auer.

Prof. Werner Lang

holds the Chair of Energy Efficient and Sustainable Design and Building at TUM and is also Vice President for Sustainable Transformation. He was previously Professor of Sustainable Building and Director of the Center for Sustainable Development at the University of Texas School of Architecture in Austin, Texas.

Picture credit: Uli Benz, Astrid Eckert