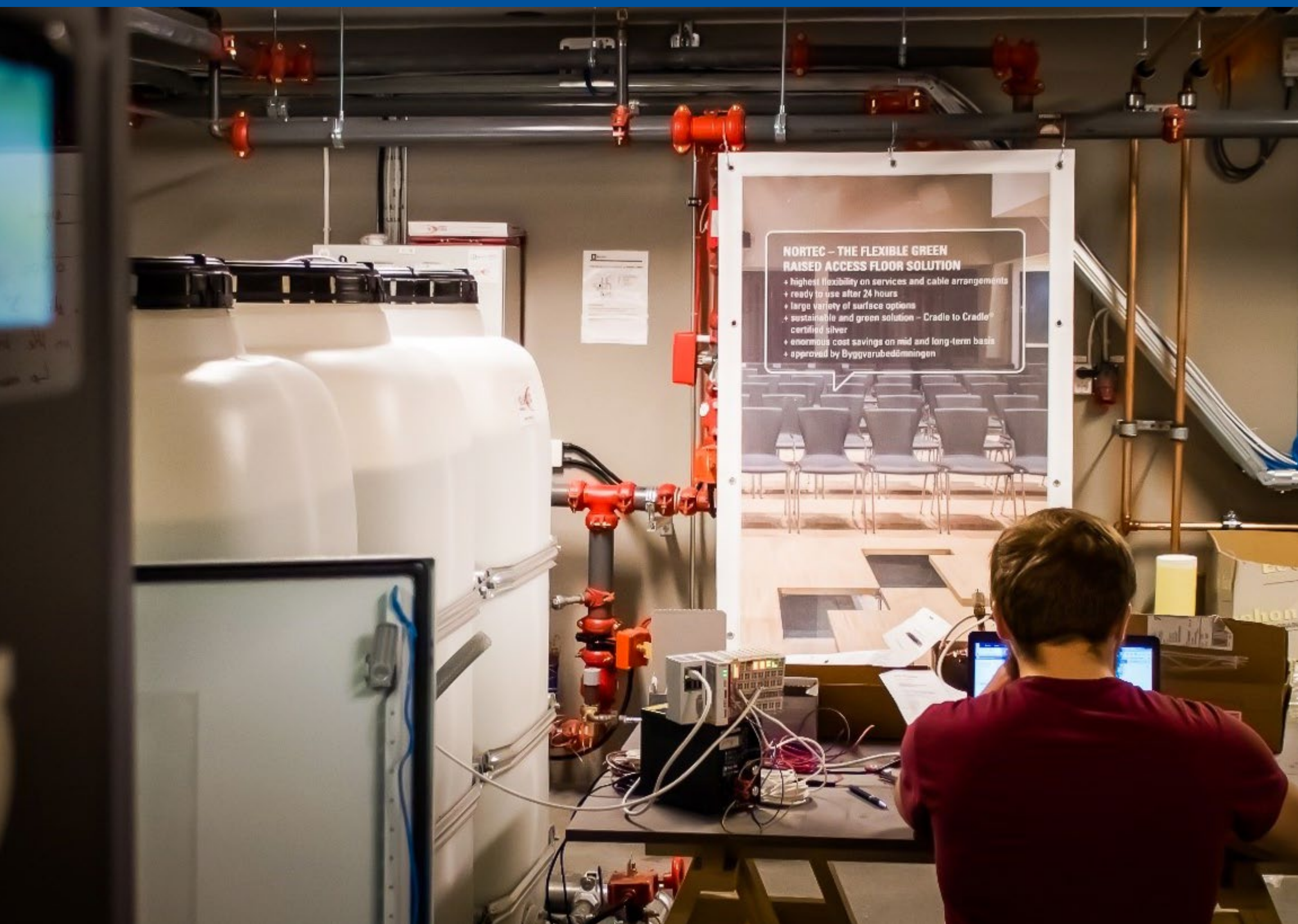
KTH VETENSKAP OCH KONST

Annual Report 2022

KTH Live-In Lab



KTH Live-In Lab in short

KTH Live-In Lab was initiated in response to the multifaceted and multi-disciplinary issues regarding the construction and use of buildings. KTH Live-In Lab has proven to work as a bridge between different research areas and between academia and industry.

Our Work

The three foundations of KTH Live-In Lab are research, education, and collaboration. KTH Live-In Lab offers something as unique as full-scale testbeds with everything from apartments in building-exempt premises to a changeable and scalable infrastructure. KTH Live-In Lab can match customer projects with researchers from relevant interest areas and create individual offers within the framework of each project. KTH Live-In Lab also enables collaboration between different study programs and with the industry, and works as a link between students and companies, which many educational programs lack today.

Our contribution

Over the years, KTH Live-In Lab has facilitated tests and collaboration in real-life environments, with real, working systems, including everything from incoming resources and technical systems to users and organizations. Thanks to KTH Live-In Lab, ideas, theories, and products can be tested in real-life systems resulting in validated research and test results on an unprecedented level.

Our Testbeds

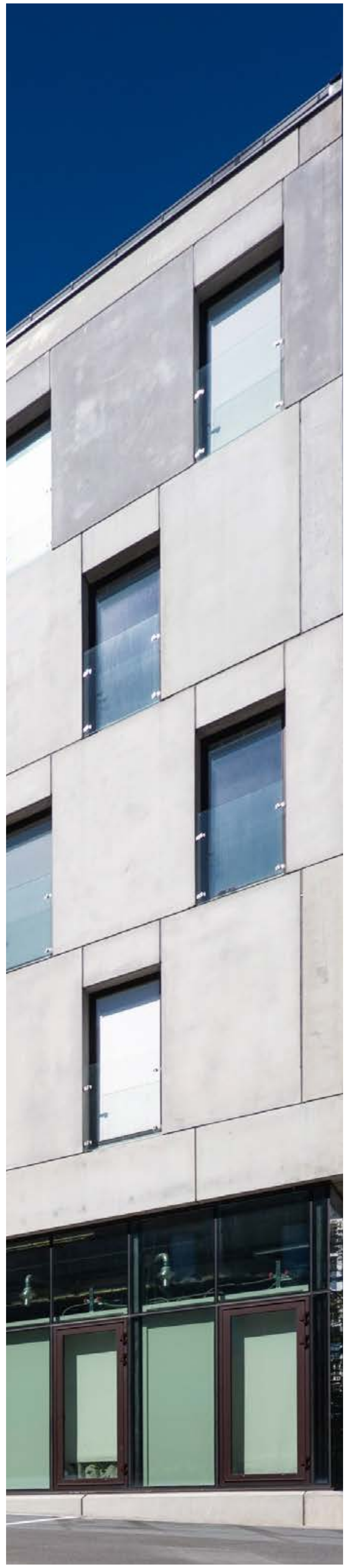
KTH Live-In Lab currently consists of three Testbeds: Testbed KTH, Testbed EM, and Testbed AH. The KTH Live-In Lab Testbeds have a joint database where data can be collected for research or educational purposes.

About us

KTH Live-In Lab is a competence center and a research infrastructure at the School of Industrial Engineering and Management (ITM). The idea behind KTH Live-In Lab came in 2013, and the concept was established during 2016 – 2017, mainly thanks to a donation from Einar Mattsson-Group.

KTH Live-In Lab became a competence centre in 2019, with KTH, Einar Mattson, Akademiska Hus, and Schneider Electric. In 2021, Bengt Dahlgren Stockholm joined KTH Live-In Lab as a center partner. We are currently around 15 active people engaged in running KTH Live-In Lab and have had more than 200 people involved in different research projects over the years.

Contents



“Learning happens in the course of the experiment itself”

Esther Dulfo, The economist as a plumber, 2017

KTH Live-In Lab – Testbed for Accelerated Innovation

KTH Live-In Lab acts as a bridge between academia and industry. The center is also a neutral arena for collaboration between small to medium-sized companies and large established companies, as well as research groups from different research areas.

Our Work

KTH Live-In Lab is an important infrastructure enabling necessary research required to tackle the multidisciplinary challenges related to buildings, services and climate change. KTH Live-In Lab functions as a collaboration platform and infrastructure, generating both knowledge, results and commitment.

Visits to KTH Live-In Lab by ministers, royalty and TV celebrities show that what we do here appeals, touches, and leads to sustainable changes in our built environment. Being asked to give an introductory speech at “Forskarfredag” in front of thousands of middle and high school students shows that what KTH Live-In Lab does is not only of academic interest, but it also affects and can influence everything from children and young people to researchers and politicians.

Our Vision, purpose, and goals

KTH Live-In Lab is a platform that handles multiple Testbeds for accelerated innovation and development of sustainable solutions in the built environment. The purpose of KTH Live-In Lab is to reduce the lead times between testing, research results and market introduction. By doing this, KTH Live-In Lab aims to enable the sustainable and resource-effective buildings of the future. The goal of KTH Live-In Lab is to help accelerate the introduction rate of new competitive and sustainable products and services for the construction and real-estate sectors.

KTH Live-In Lab's structure

Our organization and management

Although KTH Live-In Lab is located within the ITM school, the center currently has a board and management team consisting of people from ITM (School of Industrial Engineering and Management), ABE (School of Architecture and the Built Environment) and EECS (School of Electrical Engineering and Computer Science).

Our Management groups

The steering group currently consists of Per Lundqvist, professor KTH ITM, chairman, Karl-Henrik Johansson, professor KTH EECS, Martin Fors, property manager, Einar Mattsson, Richard Petersson, area manager at Akademiska Hus, Erik Bolander, CEO at Bengt Dahlgren Stockholm, and Roger Larsson, sale manager at Schneider Electric.

The executive group of KTH Live-In Lab helps carry out the center's activities in accordance with the business plan, partner agreements and the center's rules of procedure. The executive group is also in charge of assessing received applications regarding requests to conduct research or education within the framework of KTH Live-In Lab.

The executive group currently consists of Agnieszka Zalejska Jonsson (ABE), Davide Rolando (ITM), Marco Molinari (ITM), Folke Björk (ABE), Tobias Oechtering (EECS), Ute Besenecker (ABE), Cyril Holm (Stockholm University), Linda Teng (Akademiska Hus), Christer Larsson (Bengt Dahlgren) Micke Dimadis (Einar Mattsson) and Valentin Monteiro (Schneider Electric).

During 2021–2022, KTH Live-In Lab also had two part-time lab assistants (Anund Baltiswiler, Melpomeni Petrou).

Our research fields

During 2022, KTH Live-In Lab as the intermediate link between academic research and industry, classified the lab's projects in its major fields of activity in order to effectively manage, promote and support them.

The lab's projects, due to their multidimensional goals, may belong to more than one research field enabling the multifaceted work of the researchers. The projects could be categorized but are not limited to one of the following research fields:

- infrastructure and innovation
- resource management
- behavioral change and social responsibility.

Infrastructure and Innovation

The first major sector of the lab consists of projects which are related to both the physical and digital infrastructure. In more detail, KTH Live-In Lab physical infrastructure are the three Testbeds: Testbed KTH, Testbed EM, and Testbed AH. The joint database, where data can be collected for research or educational purposes, is part of the digital infrastructure of the lab. The projects of this sector aim to upgrade the products and services of the construction and real- estate sectors.

Resource Management

The second sector of the lab consists of projects which focus on the sustainable consumption of resources such as water and energy. The projects of this sector are developed on the lab's physical and digital infrastructure, especially on the Testbed KTH utilizing the data of the lab's database. Modern management methods and state-of-the-art technological equipment are exploited in the optimal way with the aim of rational use of precious resources fostering innovation.

Behavioral Change and Social Responsibility

KTH Live-In Lab has innovative projects that have social ramifications and focus on social sustainability by studying human habits and behavioral changes towards sustainability. This interesting sector of the lab puts the users of the infrastructure on the focal point examining their needs and preferences.

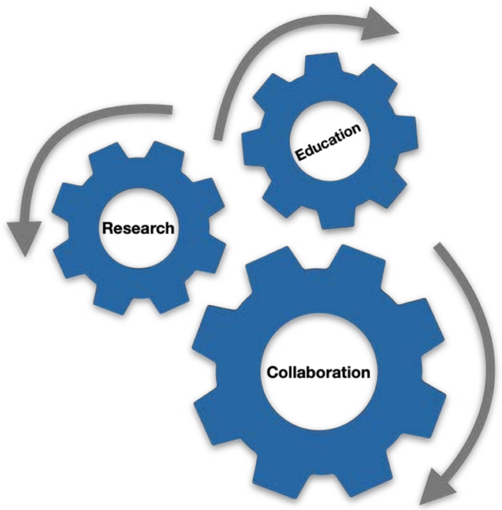


Figure 1: KTH Live-In Lab for Research & Development.

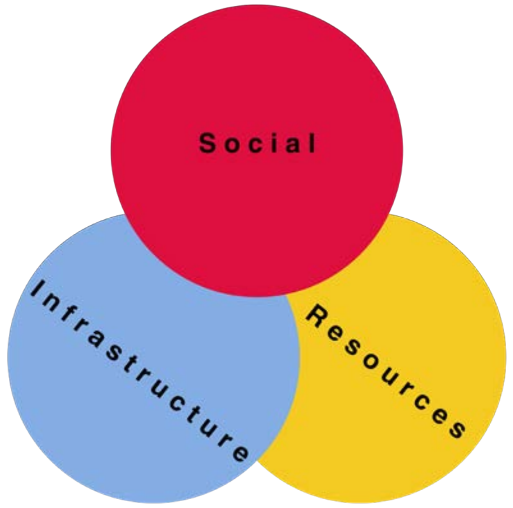


Figure 2: KTH Live-In Lab's fields of Reserch.

Our Team

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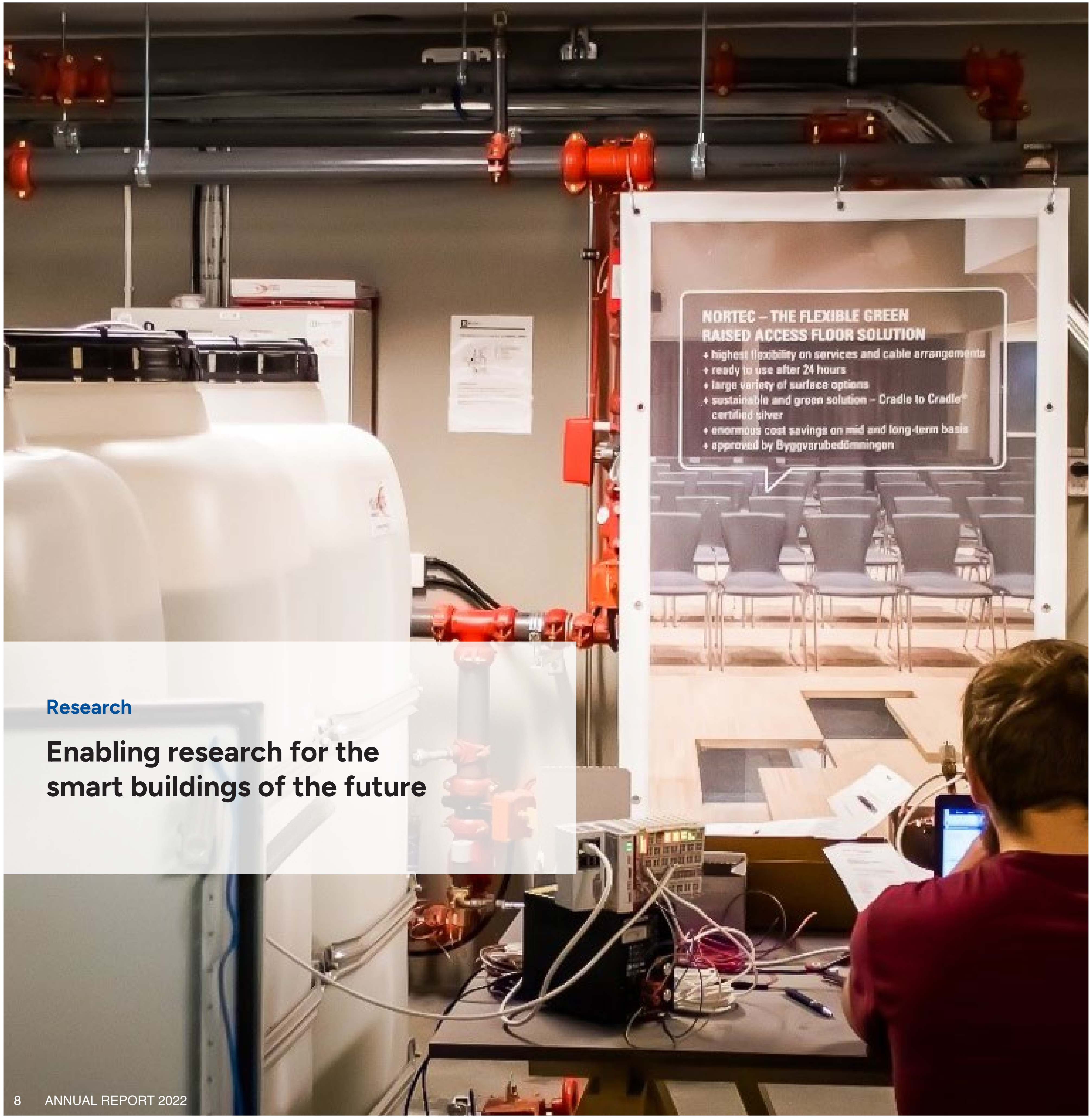
Summary of the period 2021– 2022

2022 was a year of collaboration, evolution and learning for KTH Live-In Lab. During the centers lifespan (from 2016 to 2022), KTH Live-In Lab has enabled research to a value of at least 110 million SEK and attracted donations of a total value of at least 25 million SEK. Simultaneously, KTH Live-In Lab has received a total of 4 million SEK in financial support from KTH, hence a value-generating factor of 27.5!

In 2022, KTH Live-In Lab has also actively worked with the development of routines, models, websites, and processes, and shared these with other competence centers both within and outside of KTH, nationally as well as internationally. Collaboration is the only way forward to solve the multidisciplinary challenges the built environment is facing. It's important to note that the lab through a detailed review has recognized the difficulties of bridging academic research and industry and is ready to overcome them fostering innovation.



Research

Enabling research for the smart buildings of the future

Research at KTH Live-In Lab

In 2022 there were a total of 16 ongoing projects within KTH Live-In Lab. The ongoing projects are a result of collaboration between industry and academia. The projects that were successfully completed during 2022 fostered innovation with their transparent, validated and significant results.

Most of the projects initiated by KTH Live-In Lab are challenge-driven and explore opportunities related to new theories, products, and services. Some projects are idea-driven rather than challenge-driven.

In challenge-driven projects, KTH Live-In Lab actively works with bringing forward new innovative theories, products, and services, and to enable collaboration within academia and between academia and industry. In idea-driven projects, KTH Live-In Lab actively works to manage the projects to ensure they are aligned with the challenges KTH Live-In Lab exists to overcome.

KTH Live-in Lab's operation is focused on:
1) acting as a platform for collaboration through enabling multidisciplinary research and
2) running testbeds and a database.

Our projects for 2022

Until 2022 KTH Live-In Lab has received 96 applications for use of the Testbed. Out of these, 89 applications were approved for use of the Testbed infrastructure. Moreover, 48 of these projects have been initiated, 28 projects have been completed, and 16 are still ongoing.

The initiated projects at KTH Live-In Lab during 2022 have an estimated total value of 206 million SEK, divided into 26 million SEK of co-funding and 180 million in applied funding. Additionally, the center has received a total of 22 million SEK through various donations as well as materials and technology to a total value of 5 million SEK.

The applicants include both research groups from across KTH (Architecture, Building Technology, Electrical Engineering, Energy Technology, Philosophy, Automatic Control, Real Estate and Construction Management and Information science and Engineering) and SMEs and larger corporations such as KTH Live-In Lab's strategic partners Akademiska Hus, Ericsson and other innovative companies such as Schneider Electric, Northvolt, Nordic Choice Hotels, Einar Mattsson and HSB Living Lab.

Other collaborative partners include Karolinska Institutet, Karolinska University Hospital, Stockholm University, Umeå University, Chalmers, Lund university, AMS Institute, MIT, University Technology Sydney, Max Planck Institute, and Florida University.

Read more about the projects:
www.liveinlab.kth.se/projekt

Table 1 – Summary of projects in the KTH Live-In Lab

Projects	2015	2016	2017	2018	2019	2020	2021	2022	Total
Applications	3	17	13	10	8	18	10	17	96
Started	2	1	2	9	13	7	5	9	48
Finished	0	0	3	3	5	4	8	5	28
Ongoing 2022								**16**	

Table 2 – Projects in the KTH Live-In Lab in 2022

Projects		Project Manager	Companies / Organizations	Status
2213	UNITE! Living Labs and sharing of infrastructures	Jonas A. Vogel	Technische Universität Darmstadt, Aalto Universitetet, KTH, University Grenoble Alpes, Politecnico di Torino. TU Graz, Universitat Politècnica de Catalunya, BarcelonaTech (UPC), Universidade de Lisboa, Wroclaw Tech	Finished
2212	Optimal flow rate for maximizing ground source heat pump performance	Willem Mazzotti, Alberto Lazzarot-to, Maria Letizia Fascí, Kathy Han-nun, Björn Palm	KTH, Thermia, ToM Energy Consulting Company, Unige, Sindeq borrteknik AB, Rototec, Asplan Viak, Dandelion, Bengt Dahlgren AB, NIBE, HP, Nowab, Wilo	Ongoing
2211	Boosting energy saving competences	Yavor Paunov	KTH, KTH LIL SSSB, EM	Ongoing
2210	Datasets for education	Jonas A. Vogel	KTH LIL, Digitalisation platform, KTH Sustainability	Ongoing
2209	H + Forest	Linda Teng, Agnieszka Zalejska Jonsson, Misse Wester	KTH LIL, Akademiska Hus	Ongoing
2208	Digital twins	Marco Molinari	KTH LIL	Ongoing
2206	Heat by Data cost-effective AI-driven integration of mobile network to the built environment"	Hatef Madani	KTH, Ericsson, NOW-AB, ETM Kylteknik	Ongoing
2205	Development of semantic data infrastructure for smart building monitoring system: preliminary study	Jonas A. Vogel	KTH LIL, SISAB, Schneider Electric	Ongoing
2203	Improved energy efficiency for waste recycling	Jörgen Wallin	KTH/ Energiteknik	Ongoing
2202	Thermal Energy Storage Solutions	Saman Nimali Gunasekara, Qian Wang	KTH- ITM (EGI) & ABE	Ongoing
2108	Buildings Post Corona	Jonas A. Vogel	KTH LIL, Umea University, Chalmers, Lund University	Ongoing
2107	Optimal operation of smart buildings through collaboration: Legal, economic, and organizational tools	Jonas A. Vogel, Cyril Holm	KTH LIL, Bengt Dahlgren	Ongoing
2106	Hive	Anna Khartseva	Charles Strand Design AB	Finished
2104	Cyber-secure learning control systems	Marco Molinari	KTH LIL	Ongoing
2103	Humanizing the Sustainable Smart City (HiSS)	Marco Molinari	KTH LIL, KTH Digital Futures	Ongoing
2016	Distributed Sensing Lab – Collaboration between KTH and High schools	Jonas Anund Vogel, Davide Rolando,Helena Lenholm, Susanne Engström	KTH LIL	Ongoing
2012	Sonic interaction design to support energy efficiency behavior in the household	Sandra Pauletto	KTH EECS Media Technology and Interaction Design	Ongoing
2003	Turnkey solutions with PV and energy storage (PV+ BESS in KTH Living Lab)	Rafael Guédez, Monika Topel	KTH	Ongoing
1908	Co-kitchen	Sara Ilstedt	KTH Green Leap	Finished
1703	Smart Meter Privacy with Real Energy Storages	Tobias Oechtering, Daniel Månsson, Henrik Sandberg	KTH	Finished
1611	Living in Smart Buildings LiSB	Marco Molinari, Davide Ronaldo	KTH, SU, KTH LIL, Akademiska Hus	Finished

Results from projects at KTH Live-In Lab

In 2022, the projects conducted at KTH Live-In Lab resulted in several scientific articles, including a conference paper, a doctoral thesis, a symposium contribution, three conference contributions and three final reports. The scientific papers and reports cover a wide range of research areas.

Research areas for projects:

- Management of Smart buildings and smart home services
- Building automation and resource efficiency improvement
- Building energy performance and energy savings
- Indoor environmental quality
- Use of buildings, behavior and building management
- Collaboration platforms and Living Labs
- Co-living and sharing of spaces and services

Scientific Articles and Reports

Cost- and Energy-Efficient Control Systems for Buildings

Project manager: Marco Molinari
Researchers: Katarina Bäcklund, Davide Rolando

Project description

This project, funded by the Swedish Energy Agency through the E2B2 programme, aims at demonstrating cost-effective solutions able to increase the system energy efficiency. Databases of high-resolution and high-quality data can lead to new valuable insights and the creation of new opportunities. Research testbeds offer unique resources to develop and test smart monitoring and control solutions that have a valuable impact on increasing the energy-efficiency in the built environment.

This project exploits the high-resolution, real-time data gathered in the KTH Live-in Lab research testbed through an advanced sensor and data infrastructure, in order to evaluate the cost-effectiveness of smart buildings. As a result, the operative definition of smart building is enabled. Sensor measurements are used to identify common faulty settings in buildings' ventilation and heating systems, estimating their impact on the energy use. Particular attention is dedicated to the user experience, the impact of the users' energy use, and visualization techniques to promote energy-efficient behaviours.

Implementation

Three building facilities are used as implementation and prototypes: The KTH Live-In Lab's Testbed KTH, Undervisningshuset and the neighbourhood of Uppsala Backe.

The first round of data analysis is carried out in the Testbed KTH and Undervisningshuset; this will help to identify the room for improvement in both buildings and support the design of the ICT infrastructure in Botrygg's Uppsala Backe.

Real-time user feedback: monitoring campaign in student apartments

We have created a user-friendly web-app; people in a building can use it in real-time to provide a feedback about their perceived indoor comfort. This feedback helps buildings operators to improve the wellbeing of the building users. The web-app is currently being used by the students living in the four apartments in the Live-In Lab Testbed KTH. The students use the web-app to respond when they think it is too cold, too warm, too noisy or to let us know some other aspects about their indoor comfort.

This research is carried out within the Cost- and Energy-Efficient Control Systems for Buildings project. The purpose is to evaluate the relation of users – indoor comfort – sensors – control systems and energy efficiency and to ultimately provide more comfortable and sustainable living spaces

Campaign

This campaign scales up the pilot test study in the Live-In Lab Testbed KTH to test the web-app on the Akademiska Hus student apartments at KTH, Draconis. People living in the apartments are free to use the mobile app and provide real-time feedback about perceived indoor comfort. We also envision to organize informative workshops to discuss people response and improvements of the app. A non-intrusive sensor module will be installed in the participants' apartment, monitoring temperature, relative humidity and air quality, and optionally energy use. All data will be anonymous and only used for the purpose of the research project, and participants are free to leave the study at any time.

Publications

- M. Molinari, D. Rolando, Digital twin of the Live-In Lab Testbed KTH: development and calibration, IPBSA BuildSim-Nordic 2020 Conference, Oslo (online), Norway, 2020.
- D. Rolando, M. Molinari, Development of a comfort platform for user feedback: the experience of the KTH Live-In Lab, ICAE International Conference on Applied Energy, ICAE2020, Bangkok (online), Thailand, 2020.
- M. Molinari, J. A. Vogel, D. Rolando, Using Living Labs to tackle innovation bottlenecks: the KTH Live-In Lab case study, MITAB 2021
- M. Molinari, D. Rolando, A. Lazzarotto. Energy and indoor environmental quality monitoring of a lecture building: preliminary results from the KTH Live-In Lab Testbed AH, MITAB 2022
- K. Bäcklund, M. Molinari, P. Lundqvist, P. Karlsson, Showcasing the First Steps Towards a Digital Twin for Campus Environments, BuildSim Nordic 2022:10th BuildSim Nordic conference and the 2nd International Nordic conference for IBPSA, Copenhagen, Denmark, 2022.
- Rolando D, Mazzotti Pallard W, Molinari M., Long-Term Evaluation of Comfort, Indoor Air Quality and Energy Performance in Buildings: The Case of the KTH Live-In Lab Testbeds. Energies. 2022; 15(14):4955. doi.org/10.3390/en15144955
- M. Farjadnia, A. Alanwar, M. U. B. Niazi, M. Molinari, K. H. Johansson, Robust Data-Driven Predictive Control of Unknown Nonlinear Systems using Reachability Analysis. European Control Conference, ECC2023, Bucharest, Romania, 2023 (accepted).
- A. Fontan, M. Farjadnia, J. Llewellyn, C. Katzeff, M. Molinari, V. Cvetkovic, K. H. Johansson, Social interactions for a sustainable lifestyle: The design of an experimental case study, 22nd World Congress of the International Federation of Automatic Control, IFAC2023, Yokohama, Japan, 2023 (accepted).
- M. Farjadnia, A. Fontan, A. Russo, K. H. Johansson, M. Molinari, What influences occupants' behavior in residential buildings? An experimental study on window operation in the KTH Live-In Lab, 7th IEEE Conference on Control Technology and Applications, CCTA2023, Bridgetown, Barbados, 2023 (accepted).
- M. Molinari, J. A. Vogel, D. Rolando, P. Lundquist, Using living labs to tackle innovation bottlenecks: the KTH Live-In Lab case study, Applied Energy, Volume 338, 2023. doi.org/10.1016/j.apenergy.2023.120877

Adversarial Inference control in Cyber-Physical Systems: A Bayesian Approach with Application to Smart Meters

Smart Meter Privacy with Real Energy Storages

Researchers: Ramana R. Avula (Student Member, IEEE), Tobias J. Oechtering (Senior Member, IEEE), and Daniel Månsson (Work to be submitted soon to IEEE Access)

Main research questions

Smart meter contains information about the daily life and activities of the consumers, which may include sensitive information that should not be shared. A manipulation of the smart meter reading using energy management strategies is a promising privacy-by-design approach to enhance consumers privacy. The main research question is how to enhance the technology readiness of such approaches?

The design of energy management strategies with provable privacy guarantees is challenging since small characteristics in the energy profile can reveal appliances. To enhance the technology readiness of existing approaches, experiments and designs of strategies with real consumer data are necessary.

Case studies

Collect and make available relevant energy consumption data in the KTH Live-In Lab that can be used for the design of privacy-preserving energy management strategies.

Results

In this project, we created datasets of energy consumption profiles in a co-living student apartment, which is so far not available. The dataset focus has a focus on privacy sensitive appliances as well as larger consumers which are used for disaggregation. Moreover, the dataset contains reference data that enables a quantitative performance assessment of the approaches and therewith enables further research. In our most recent research work, we have used the real smart meter data for the first time to design privacy-enhancing energy management strategies using a reinforcement strategy to learn the optimal control policy. The work will also give a comprehensive description of the data set and its setup.

Read the report: https://www.liveinlab.kth.se/en/projekt/r-d-projects/energy-storage-for-smart-meter-privacy-1.980434

Read the relevant Doctoral Thesis: http://kth.diva-portal.org/smash/get/diva2:1754000/FULLTEXT03.pdf

Pathways to the Smart Building Era

– A Mixed Method Approach to Understand Building Occupants and Unlock Organizational Bottlenecks to Achieve a trade-off Between Thermal Comfort and Energy Efficiency

A Mid-term presentation of Katarina Bäcklund's Doctoral Thesis "Showcasing the First Steps Towards a Digital Twin for Campus Environments"

Katarina Bäcklund is an industrial doctoral student conducting her doctoral thesis in a collaboration between Akademiska Hus and the KTH Department of Energy Technology, with KTH Live-In Lab as an important partner.

The use of digital landscapes is a challenge for the Real Estate Industry, putting the users and their experience as a priority. Katarina Bäcklund's research contributes to the optimal management of data in common shared smart buildings.

When did your collaboration with KTH Live-In Lab start, and in which ways are you involved in the Lab?

I started my collaboration in 2018 and I have participated in several projects within the KTH Live-In Lab platform. I started working for the research project GDPR and Smart Buildings funded by Smart Built Environment. This project was about the new General Data Protection Regulation (GDPR). The research project focused on how this new EU data protection law could affect smart buildings. Then I started working for the Multiple testbeds research project within the concept KTH Live-In Lab. Lately, I was also involved in Cost- and Energy-Efficient Control Systems for Buildings, funded by Energimyndighetens E2B2 program.

For Cost- and Energy-Efficient Control Systems for Buildings we developed and tested measurement boxes for temperature and CO_2 together with an app that students could use to give feedback about their perceived indoor comfort. The tests were performed at KTH Live-In Lab's testbeds and Akademiska Hus student apartments at Teknikringen. Right now, I am focusing on Akademiska Hus Digital Twin and part of my recent research was published in 2022.

I wrote a conference paper; "Showcasing the First Steps Towards a Digital Twin for Campus Environments" that I presented in the international conference BuildSim Nordic 2022. The paper described the designing method of a Digital Twin for campus environments.

What is an accurate definition of a Digital Twin (DT) for you?

DTs are established in the manufacturing industry and aerospace, but it's a rather new concept for the building industry. There's no unified definition and there are several ways of interpreting a DT. It is also quite complex as DTs are often confused with BIM models, digital shadows or digital models.

My purpose is not to come up with a new definition, therefore I have used a suitable definition, already published by an IT-consultancy: "A Digital Twin is a digital representation or a digital instantiation of a physical object, process or a system that is used for various purpose. It includes the virtual model of the physical object, data from the object, a unique one-to-one correspondence to the object and the ability to monitor the object. Through a combination of data and intelligence that represent the structure, context and behaviour of a physical system of any type, it offers an interface that allows one to understand past and present operation, and make predictions about the future" (Gavstech, 2017).

What challenges of using a Digital Twin have you identified?

If you look at the DT that Akademiska Hus is developing, one of our main challenges is how to keep it updated because buildings change over time as they are renovated or redecorated. Thereby, the building industry faces the challenge of updating DTs in a cost-efficient way. DTs are also data heavy, so they require a lot of data storage. This is also where one important sustainability aspects arise, since the requirement of large data centers, is very energy demanding.

Another important challenge that is yet not understood is to realize the full potential of digital twins for the built environment.

Who could benefit from using a Digital Twin?

A DT could be useful for any building stakeholder. It could be useful for the designers, for the construction phase, it could be useful during the operational phase and during the demolition stage and recycling. A DT should contribute to sustainable buildings and fill a purpose during every phase of a building.

My research focuses on the operational phase of the building. The key stakeholders are the building occupants i.e., the students. For example, I study how the DT could be accessible through a mobile app. For instance, the DT could provide you directions to find a room, if you are at a big campus, it's not always easy to locate yourself. Or you could also use a mobile digital twin to find an available room to study. Furthermore, DTs could make it easier for users to contact the building managers if something is broken or malfunctioning.

One of the research aims for your doctoral thesis is to achieve a trade-off between thermal comfort and energy efficiency. In which way could a Digital Twin facilitate this trade-off?

From the users perspective, people often lack information regarding the building systems, for instance what kind of impact their behavior has. From building operators or building managers perspective, it's important to make sure that the buildings are running efficiently, and a DT could provide valuable information. Building operators currently have to use multiple platforms to get the essential information and they check every system separately. The DT provides the opportunity to gather all the systems in only one platform. With a DT a building operator could collect all the data from these various systems easily, have a better overview, detect and repair faster any malfunctions.

Bäcklund, K., Molinari, M., Lundqvist, P., & Karlsson, P. (2022). Showcasing the First Steps Towards a Digital Twin for Campus Environments. E3S Web of Conferences, 362, 10003. https://doi.org/10.1051/e3sconf/202236210003

Mid-term Seminar: www.liveinlab.kth.se/polopoly_fs/1.1234251.1677675416!/Mid-Term%20Seminar%20Katarina%20Bäcklund%202.pdf

Digital Twins for Industry

Digital Twins from Bengt Dahlgren's prespective, Shima Dehvari

What is a Digital Twin?

A Digital Twins (DT) is a technology used to create a virtual representation of a physical reality. This representation can be used to collect, store and analyze data from a variety of sources, including sensors, machines and people. Information collected via a digital twin can be used to create value for the company by helping to improve efficiency, reduce costs and increase the quality of products and services. This, in turn, can lead to new business models and business opportunities.

Value and business opportunities

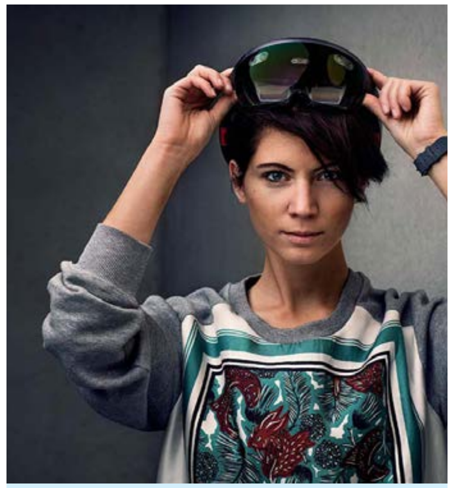
DT can be used to optimize energy consumption in buildings and industrial processes by collecting data from sensors and analyzing it to identify opportunities for improvement. This can lead to savings in energy costs and help reduce carbon emissions. DT allows you to address risks at an early stage before they lead to injuries and accidents. It can identify any flaws or errors in the design or construction and help improve the performance and safety of the building. DT can be used to track and trace products and equipment throughout their life cycle, from manufacture to decay. This can help E&C to plan for maintenance and repairs and extend the life of products/equipment and the building. Customers and tenants have the opportunity to see their premises and influence the design before it is built.Other benefits include predictive maintenance, product development, smart buildings, increased accessibility and quality.

Challenges related to Digital Twins

DT relies on high-quality data to accurately simulate physical systems. If data collection is not reliable or not regularly updated, DT can fail. DT requires the integration of multiple systems and technologies to function properly. The creation of DT requires a detailed understanding of the physical system to be modeled. The more complex the model, the more difficult it will be to create and manage. Other challenges are security and cost.

End-user activity-based service design in the built environment context:
Exploring everyday life in KTH Live-In Lab

Elena Malakhatka's Doctoral thesis KTH,
School of Industrial Engineering and Management (ITM)



Elena Malakhatka is a Postdoctoral researcher at Chalmers University of Technology collaborating with HSB Living Lab. She has recently finished her doctoral research project at KTH Live-in-Lab.

How did your collaboration with KTH Living Lab start and how would you describe your experience?

I started as a PhD student who was hired by the Department of Energy Technology and practically, I conducted my doctoral thesis in KTH Live-In Lab. I was involved in several research projects, and I published 6 papers. Living Labs offer amazing opportunities to researchers who work on the intersection between human and technology. Living Labs are a new type of academic platform that allow researcher have access to infrastructure and people at the same time.

From my experience in KTH Live-In Lab, I understood that this platform is a real-life context laboratory that is evolving with the new actors, with the new themes and new projects. KTH Live-In Lab is never static it's constantly innovating itself, that is why it is a perfect testbed for the action research.

How did your research activity in KTH Live-In Lab unfold?

In the begging of my collaboration with the Lab my main research question or like exploration field was to understand how we can use data from smart buildings to make life of the individuals better. And this is a very big and broad question. Definitely, we can ask, like, what do you mean by better? Is it better for them? Is it better for economy? Is it better for environment? In this way my research field opened up on the first stage allowing me to explore what data can really give us.

I started with a focus on data and users' activities. The first paper which was published in 2019 with the title End-user activities context information management framework for sustainable building operation, was a conference paper for the CISBAT (Climate Resilient Cities – Energy Efficiency & Renewables in the Digital Era) conference where I explore daily activities, users' needs, and availability of data. That was a really good starting point to understand that smart building and Living Labs can answer a big range of questions related to everyday life.

During my research journey at KTH Live-In Lab, we explored and identified where we should focus more. That was the topic for the paper Co-Creating Service Concepts for the Built Environment Based on the End-User's Daily Activities Analysis: KTH Live-in-Lab Explorative Case Study (2021), which I wrote for the Journal of Sustainability. This paper was about how we can co-create together with users different concepts for the more sustainable everyday life.

We identified three topics: food, well-being, and space-as-a-service. It was a constant exploration thtough the action research and iterative co-creation with multiple stakeholders. In this case, research at KTH Live-In Lab is not static, it's very dynamic, it's very engaging, it's very alive, not only in methods, but also in possible research trajectories.

Action research can navigate a researcher towards relevant topics and the end results can make sense for the users. This type of results not only change people's behavior, but they help them develop new habits. A researcher can detect these changes also numerically in the way they consume energy or in the way they conduct an activity.

One of the case study was explored the everyday food-related behaviours, such as food acquisition, cooking, eating and storing or wasting food. We have started with high resolution data: what they eat, when they eat, what motivates them to buy what they're buying, which ingredients, how much, how they store it, where they're buying it, from which country of origin these products are coming from. It was really detailed data. We ended up with good appreciation from other scholars and motivation to continue the everyday food related study.

This researcher project brought me to the big Vinnova's Impact Innovation Program development project. To conclude, a small little case study from KTH Live-In Lab created resonance and had an important impact on further research.

What were the findings that fascinated you during your research journey?

First of all, I learned how difficult it is to change human behavior and how much we simplify it as engineers. There is a term in environmental science called resource man. We want to address our innovation technology and we consider of this ideal perfect person, the 'Resource man' – an individual who excels at effectively managing and maximizing available resources. In the reality it is never like that.

A lot of projects unfortunately fail because human nature is much more complicated than how engineers conceive it. A data approach is not enough, and behavior science really showed the complexity is behind us, behind a human, and that I have very little tools as engineer to really address these things. And that's what really made me to search a lot of references for what might work. If you want to design technology for homes, for humans at homes, we need to focus have both: computer science or engineering and behaviour science.

In my case my studies theory of planned behaviour applied to the energy science helped me in the food project, to study the habit formation of students. It was only for a half a year, and we can't really conclude and generalize completely what we succeed. But at least during this period, we saw the environmental impact from the food related activities dropping almost 30%.

Students really started to prioritize when to use home appliances, for how long to use, which recipes to use to really have low energy intensity for the cooking. You can say cooking is just 7% of household energy, but it's still an important amount of energy. I think the importance of cooking or other similar kind of activities is that they are constant. We will always need to cook, we will always need to do laundry, we will always need to use our appliances. And that's where in the long term, I see this kind of focus is important.

Talking about results and findings, it's very difficult to include human aspects and human factors into the engineering solutions. However, it's very much needed. A very important finding which I reflected a lot on my thesis, is that a lot of people try to start with environmental sustainability and use technology in order to generate changes. This won't bring a lot of results. However, my study showed clearly that a combination of social sustainability and environmental sustainability can guarantee much better results because social sustainability is pro-human. You get something back for yourself and for the planet

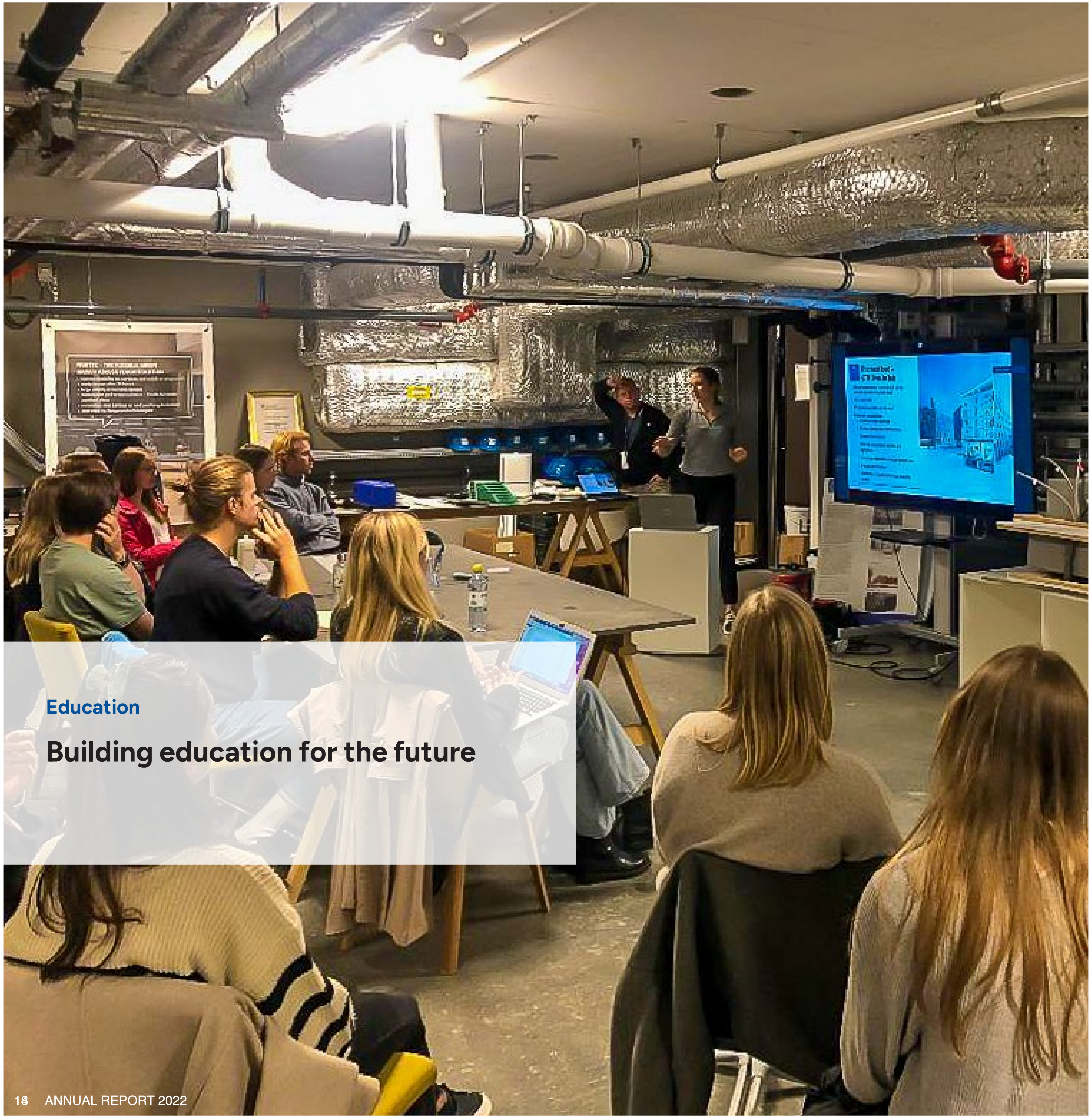
This combination, people and planet, works much better than just planet. And in the motivation part of the study, we found that a lot of students theoretically ready to consider nature and environment, but in practice it's not their priority yet. And in this case, the merging social and environmental aspects can really move environmental further rather than if we just start with only environmental.

My study I think is one of the first which really start with human-centric approach or social-centric approach, including environmental. Environmental aspect was secondary, with the hypothesis that it will go further if we just blend it with social. As example, most of the students vote for the food project because. It was not my choice it was their decision and I just followed it.

Read the Doctoral Thesis and the papers:

https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1656658&dswid=3875

- Malakhatka, E., Al Rahis, A. A., Osman, O., & Lundqvist, P. (2021). Monitoring and Predicting Occupant's Sleep Quality by Using Wearable Device OURA Ring and Smart Building Sensors Data (Living Laboratory Case Study). Buildings, 11(10), 459. https://doi.org/10.3390/buildings11100459
- Malakhatka, E., & Lundqvist, P. (2019). End-user activities context information management framework for sustainable building operation. Journal of Physics: Conference Series, 1343, 012151. https://doi.org/10.1088/1742-6596/1343/1/012151
- Malakhatka, E., Lundqvist, P., Shafqat, O., & De Bellefon, A. (2022). Identification of everyday food-related activities with potential for direct and indirect energy savings: KTH Live–in–Lab explorative case study. Energy Policy, 163, 112792. https://doi.org/10.1016/j.enpol.2022.112792
- Malakhatka, E., & Per Lundqvist. (2022). Actors' Network Analysis and Bi-Directional Value Exchange Matrix Development for Living Labs: KTH Live-In-Lab Case Study. 139–147. https://doi.org/10.1007/978-3-030-97042-0_14
- Malakhatka, E., Sopjani, L., & Lundqvist, P. (2021). Co-Creating Service Concepts for the Built Environment Based on the End-User's Daily Activities Analysis: KTH Live-in-Lab Explorative Case Study. Sustainability, 13(4), 1942. https://doi.org/10.3390/su13041942
- Shafqat, O., Malakhtka, E., Chrobot, N., & Lundqvist, P. (2021). End Use Energy Services Framework Co-Creation with Multiple Stakeholders—A Living Lab-Based Case Study. Sustainability, 13(14), 7565. https://doi.org/10.3390/su13147565



Education

Building education for the future

Education at KTH Live-In Lab

KTH Live-In Lab provides essential input to courses and theses internationally. The growing interest in the work of the laboratory is reflected in the increasing number of site visits by students and researchers from all over the world.

The interest in using KTH Live-In Lab in courses and theses is big and growing. So far, the involvement in courses has been limited to site visits, workshops and presentations / lectures. The aim is to develop course packages that can be included in already-ready existing courses at KTH, focusing on cross-disciplinary co-creation.

KTH Live-In Lab provides a natural point of contact between students and the industry. KTH Live-In Lab can therefore be used as a case or project assignment in course curricula at KTH. This gives students from different study programs the opportunity to contribute to the evaluation and validation of tests currently in progress in the Testbeds. Students are also given the opportunity to collaborate with the team designing the constellation of the innovation-area in the Testbeds for the coming year.

Courses

In 2022 KTH Live-In Lab initiated the two projects "Datasets for education" and "Datasets for research", designed to serve the needs of students, professors and researchers. KTH Live-In Lab also continued to develop as a learning enviroment and collaboration partner for researchers, students and industry.

Courses that visited or used KTH Live-In Lab during 2022

AF2507
Sustainable Buildings – Concept, Design, Construction and Operation, Ivo Martinac, KTH ABE

AG1815
Sustainable Development, ICT and Innovation, Anna Björklund, KTH ABE

AI1145
Property Management with a Financial Perspective, Agnieszka Zalejska Jonsson, KTH ABE

AI1146
Property Management, Agnieszka Zalejska Jonsson, KTH ABE

MJ1141
Energy Systems and Sustainability, Per Lundqvist, KTH ITM

MJ2146
Energy Systems, Business and Management, Per Lundqvist, KTH ITM

MJ2443
Heating, Cooling and Indoor Climate, Samer Sawalha, KTH ITM

Master degree project in Energy Engineering
Davide del Col, University of Padua

Erasmus + EUSL-ENERGY
Programme of the European Union

Cases and case studies

KTH Live-in Lab recognizes the importance of an experimental learning environment. A smaller incentive package has been designed to support courses that use KTH Live-In Lab as a case study. A part of the package contains introductory lectures from KTH Live-In Lab, and contributions to the exhibition or catalogue. KTH Live-in Lab supports dissemination of knowledge and exchange of information through different channels.

Lifelong Learning

KTH Live-in Lab is exploring forms in which Lifelong Learning could be further developed. Current collaboration with fastighetsbranschens Utbildningsnämnd reveal the great need of technical competence for managing smart and sustainable future. A need that currently cannot be sufficiently met through higher education, vocational higher education or other education providers. However, to harvest the benefits of digitalization there is a need for collaboration also around education.

Institutes / organizations that visited or used KTH Live-In Lab during 2022

- Amsterdam Institute for Advanced Metropolitan Solutions (AMS)
- Delft University of Technology
- Engineering school ECAM LaSalle
- Lund University
- Rocky Mountain Institute
- Rutgers University
- Sintef
- Swedish Energy Agency
- Swedish Real Estate Association's Education Committee
- UNITE! University Network for Innovation, Technology and Engineering
- Uppsala University

PROJECT

Datasets for education

The purpose of the project is to make data from buildings in the KTH Live-In Lab available for use in teaching at KTH.

Aims and Objectives

The project aims to:
1) identify which datasets are desirable
2) develop identified key datasets and at the same time develop a structure for making other datasets available.

The objectives are to make data available in a simple and efficient way for use in education and lifelong learning and further education courses. This enables students to develop digital excellence, increase understanding of how digital tools can be used and actively contribute to achieving both global sustainability goals and KTH's sustainability goals.

Project's Datasets

The datasets can also be used as case studies, accompanied by a smaller incentive package to support courses that use data. The package clarifies the expectations for the parties involved and includes the offer of introductory lectures from KTH LIL, contributions to the exhibition/catalog and knowledge dissemination via web and information exchange at conferences and workshops.

The project helps to create digital experimental environments that teachers and students can use to develop skills for innovative and sustainable engineering.
The intention is that courses involving data from KTH will be implemented in different ways in KTH LIL, e.g. through annual rebuilding of the innovation units in Testbed KTH, optimization of automation, or new services. This means that student work and knowledge is used directly to increase sustainable resource use and sustainable construction.

Action plan

- Interviews with teachers and researchers at KTH about which datasets are of interest for different courses. The target group is teachers (course coordinators/examiners) in: ITM, ABE, EECS school.
- Compilation of data needs and dataset preparation
- Data downloading, data management, metadata generation, anonymization, etc.
- Compilation and availability of datasets (KTH cloud service and KTH LIL website)

If time/resources are available, this is carried out within the framework of the project:

- Development of a communication package including introductory lectures, data description, site visits
- Development of communication material for teachers/course coordinators.

Sustainability

Designing buildings for the future

"The buildings of the future compose sustainable cities where people actively and vibrantly engage with their physical and non-physical environment meeting the challenges of climate crisis."

Sustainability

KTH Live-In Lab enables sustainability transformations and reinforces the sustainability work at KTH. KTH Live-In Lab approves only the projects that aim to foster sustainability.

The multidisciplinary nature of buildings, the ongoing digitalization and the future energy and environmental goals are all major challenges. By bringing together academia and industry, KTH Live-In Lab increases the opportunity for external funding and creates win-win situations. Increasing the pace of innovation in the public construction sector, based on excellence in research, education, and collaboration ensures that KTH becomes a sustainable campus and that Stockholm retains its leading position in sustainable urban development.

KTH Live-In Lab primarily enables projects in the following areas of the global sustainability goals:

- Health and well-being (SDG 3)
- Clean water and sanitation (SDG 6)
- Sustainable energy for all (SDG 7)
- Sustainable industry, innovation and infrastructure (SDG 9)
- Sustainable cities and communities (SDG 11)
- Sustainable consumption and production (SDG 12)
- Fighting climate change (SDG 13)
- Implementation and global partnership (SDG 17)

Infrastructure & Database

Testbeds and data for multidisciplinary research and development

Infrastructure & Database

KTH Live-In Lab is a significant puzzle piece in the work towards creating the smart and sustainable building of the future.

The idea behind KTH Live-In Lab is to offer buildings, operations, and data to enable multidisciplinary research and development. Additionally, KTH Live-In Lab aims to accelerate the pace of innovation in the public construction sector. KTH Live-In Lab has three interconnected functions, two of which are infrastructures:

- Collaboration platform
- Testbeds
- Data and IoT-platform

Testbeds

There are currently three Testbeds in KTH Live-In Lab: Testbed KTH, Testbed EM, and Testbed AH. There are also some trusted buildings that deliver data to KTH Live-In lab, for example multifamily buildings in Uppsala, buildings owned by Botrygg.

The KTH Live-In Lab Testbeds are open for all who wish to conduct research and tests on products, services or processes within an area that has bearing on the real estate and construction sectors. Research on new business models and collaboration structures are also possible.

Testbeds

KTH Live-In Lab currently consists of three Testbeds: Testbed EM, Testbed AH and Testbed KTH. The KTH Live-In Lab Testbeds have a joint database where data can be collected for research or educational purposes.

Database and data management

Data from the Testbeds are collected and shared via KTH Live-In Lab's data pool. The database is located on KTH's servers. Our data pool consists one of the most valuable infrastructure that supports research and innovation not only for KTH but also for other institutions. In 2022, the interest in our data pool increased, creating the opportunity to build new partnerships with other institutions and laboratories.

Testbed EM (Einar Mattsson)

Testbed EM consists of 305 student apartments in three plus-energy buildings, located on KTH Campus Valhallavägen. Hot water and heat are generated via heat pumps connected to 12 boreholes of a total length of 3600 meters. The Testbed has approximately 1150 square meters worth of solar panels and 64 wastewater heat exchangers.

The Testbed will also have a battery energy storage system connected to the solar panels with a capacity of around 300 kWh in collaboration with Northvolt. Hot water, electricity, CO_2, and light are measured in all apartments and the control and monitoring systems can be influenced for research purposes.

Testbed AH (Akademiska Hus)

Testbed AH consists of Undervisningshuset on KTH Campus Valhallavägen and is equipped with hundreds of sensors. These sensors measure relatively common values such as ventilation flows, CO_2 and electricity and water usage, but also moisture levels and movements in individual parts within the test bed.

Testbed KTH

Testbed KTH is in building-permit exempt premises in one of Einar Mattsson's three plus-energy buildings on KTH Campus Valhallavägen. The premises are a total of 305 square meters divided into a living area distributed over approximately 120 square meters, a space for the technology of about 150 square meters and a project office of roughly 20 square meters. Within Testbed KTH, various apartment configurations are built on an annual basis and KTH sublets these to students who have applied to live in the test apartments. The KTH Testbed is fully flexible regarding both geometry and installations. Moreover, the Testbed has its own solar panels and a borehole making it possible to change the collector. The premises are rented by Einar Mattsson on a ten-year contract, 2017–2027, but everything in the premises (the apartments, substation, and office) is owned by KTH.

What's new in Testbed KTH?

During 2022 the Testbed KTH continued to be one of the most effective shared living experiments in a smart apartment. Testbed KTH provides significant results in a wide range of research fields. In essence, this Testbed creates a channel for direct communication between researchers and students / tenants. Reliable and valuable results are produced in a fast rate thanks to the direct feedback of the tenants and their active participation.

Letter from tenants in Testbed KTH

Dear Jonas,

Our stay at the KTH Live-In Lab is a unique opportunity and we feel so lucky to be able to contribute to the lab's numerous researching programs with our presence. For us the tenants, 2022 was a year of sharing, teamwork and self-reflection as we helped each other build new sustainable habits.

In 2022 our team grew and changed as we are 5 students in the apartment. This new version of our team has a different dynamic due to the newly formulated friendships. This year we feel closer than ever, and we enjoy spending time together. We also share all the kitchen appliances and cleaning products. Every Friday we have guests, and we play a lot of board games in our spacious kitchen. Sunday is our chilling day, and we watch films in our cool living room. In our everyday life we often find ourselves studying in the kitchen where we socialize. The layout of the house is very convenient as the proportion of private and shared spaces helps us to have a happy cohabitation.

Moreover, in 2022 we discovered our recycling mistake and since then we are trying to inform other residents in Malvinas. In more detail, across the street there two different trash bins, a smaller one for composting and a bigger one for all that trash that can't be recycled. We solved the mystery of the different lids, but we have noticed that a lot of other students still seem to be confused. Thus, we suggest enriching the information on recycling on the panel located at the entrance of each building.

However, we have a few more requests. Firstly, as we all cook every day, we would love to have fresh herbs in our kitchen. Unfortunately, our efforts to have small pots are failing and that's maybe due to humidity sensors in the kitchen. In general, we would prefer having a more humid indoor environment. In addition, the existing energy crisis is one of our concerns. A common decision of ours is to reduce the temperature in the apartment especially in the morning and midday hours.

Last but not least, we would like to thank you for the new improved shower system. This shared living experience has helped us to improve, to change habits and to feel active members of the student society. Looking forward to your reply.

Kind regards,
The tenants.

KTH Live-In Lab reply

Thank you very much for the valuable feedback and the excellent cooperation. I note all your comments, I will pass them on to my colleagues and we will proceeded with the necessary changes! However, humidity is an interesting area, and we have had the same discussion every year. During the colder seasons we have the issue that cold outdoor air is heated, and hence the relative humidity for the warm indoor air decreases. This is a phenomenon occurring everywhere, but at Live-In Lab there are sensors showing just how dry the air is. It would be interesting to investigate how you perceive the indoor environment if we would change the sensors to show high humidity during dry days. The mind is a powerful tool. More flexible indoor temperature is coming.

I must also thank you all for your generosity, flexibility and interest in all our research projects. You have opened your home for ministers, commissioners, politicians, researchers from all over the world, industry representatives and also other students. This you have done with smiles on your faces, and always there to answer questions and give your input to whatever is asked.

Thank you all for a great year of learning!

KTH LIL Team
Jonas A. Vogel

Collaboration

Multidisciplinary cooperation to foster innovation

Collaboration

KTH Live-In Lab bridges academia and industry promoting collaboration between research projects and research fields.

The testbeds in KTH Live-In Lab can be used for innovative environmental technology – for research, development or education. KTH Live-In Lab offers workplaces, space for necessary installations and the infrastructure and context needed for research and development of technology in a real residential environment.

After the application process, collaboration between researchers / companies and KTH Live-In Lab is formulated and formalized. Moreover, KTH Live-In Lab promotes collaboration between research projects supporting multidisciplinary cooperation. There are different levels of collaboration.

Project collaboration

Companies and researchers use the testbeds for research and postgraduate education, basic education, assignment research or assignment training. Companies and / or researchers proceed with a project description including budget and agreement. Project collaboration can then take various forms.

Letter of Intent

Small companies, startups or researchers can obtain a 'Letter of Intent' with the aim of facilitating project collaboration, if their idea, product or service is considered relevant to KTH Live-In Lab.

Strategic collaboration

Companies may also want to collaborate with KTH Live-In Lab at a strategic level, outside the scope of the application. The purpose of a strategic partnership is to create collaboration between KTH and the business community. Strategic partners are also involved in undergraduate, research and/or postgraduate education.

Read more about our project process on our website: **liveinlab.kth.se/en/samverkan/projektprocess-pa-kth-live-in-lab-1.1064763**

How to start a project?

KTH Live-in Lab offers infrastructure and data to researchers and companies. Those interested in collaborating with KTH Live-In Lab on a project can apply on KTH Live-In Lab's website.

Application Process

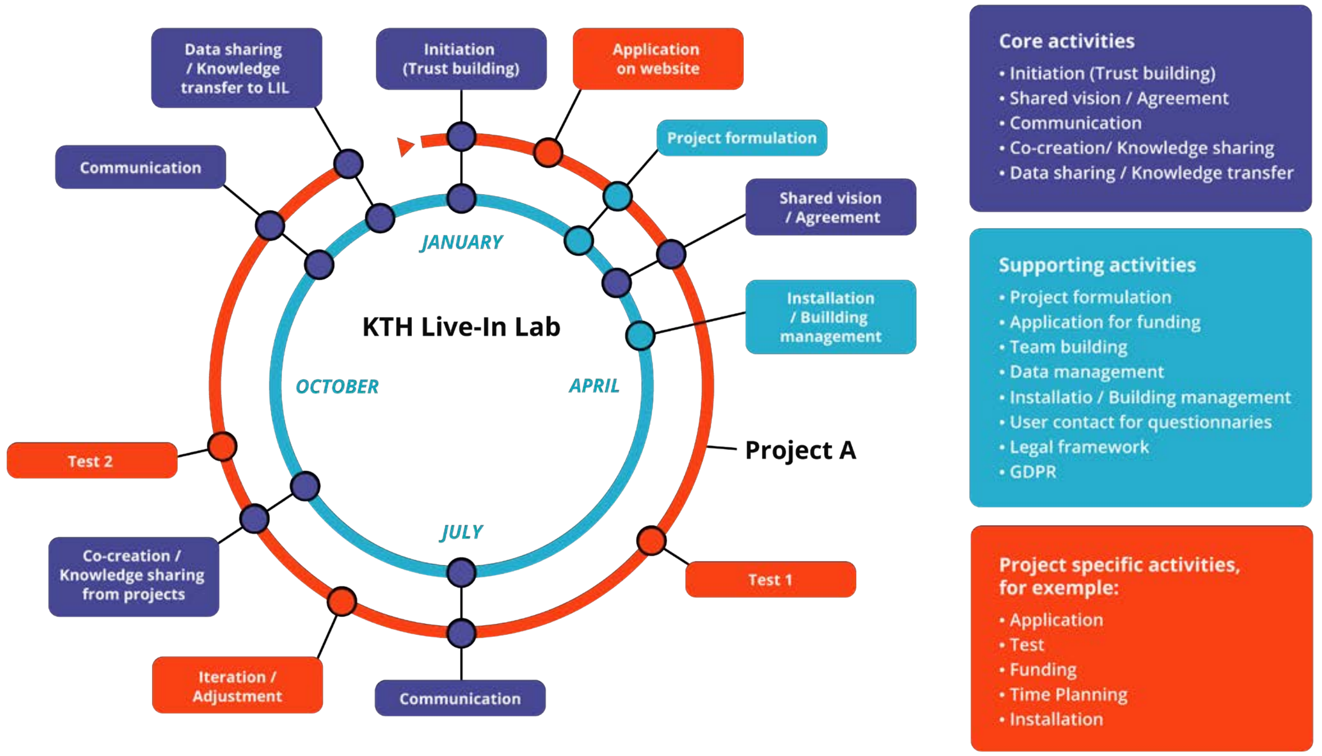
All applications must include information about the project, such as a project description and the goals and purpose of the project. Applications are reviewed by the executive group and approved by the board of KTH Live-In Lab.

If a project application is approved, the applicant will receive a letter of intent (LOI) confirming that the project can be performed in KTH Live-In Lab during a specific time, and that the project will independently pay for its costs. The project must also financially contribute to KTH Live-In Lab's operating costs. This normally amounts to between 50 000 – 300 000 SEK per year.

KTH Live-In Lab's support

The individual projects apply for funding and once the projects are finished their results are saved and stored. This enables other projects to pick up where previous ones left off.

KTH Live-In Lab will assist with all necessary installation, support collaboration between ongoing projects, handle communication and data storage. KTH Live-In Lab can also assist in applications for funding, ethical reviews and more.



The KTH Live-In Lab project process.

PROJECT

Optimal operation of smart buildings through collaboration: Legal, economic, and organizational tools

Digitalization and innovation related to materials, products and methods, among others, are making building systems more interconnected, which in turn makes our buildings and cities more 'smart'. With digital technologies, more systems can be integrated, managed and monitored, provided they can be well coordinated. Such integrated systems enable better use of resources, better data through monitoring, and better indoor comfort. They also create new services for the stakeholders who own, operate and use the buildings.

However, it has been shown that new technologies tested and verified in new test beds, such as the KTH Live-In Lab, do not reach their full potential once implemented and installed. This project therefore aims to investigate the link between new technology and optimal operation of buildings.

Project Purpose

The project aims to investigate the current context of new/smart building technologies, from design to operation, and how knowledge of these systems is transferred across phase/actor and discipline boundaries. The project goal is to create conditions for optimal operation of smart buildings.

The goal is achieved by developing proposals for adjusting e.g. project process, business models and contract forms. The desired impact is to contribute to the development of new knowledge about decision-making processes, new knowledge on process and information flow related to new/smart technologies, promoting optimal operation of buildings.

Expected results and impacts

The project is expected to result in:

- Analysis and discussion of collaborative processes for long-term benefit of knowledge from all phases. E.g. utilization of BIM, digital twins, from design to operation.
- Analysis and discussion and possible proposals on procedures for coordinated testing.
- New insights into the knowledge that must follow from client/consultant to operation.
- Proposal for developed procedures for the transfer of knowledge between clients/consultants and operations.
- Discussion of different forms of vertical integration.
- Utilizing knowledge and information throughout the construction process.
- Identification and discussion on the enabling of new services and business models related to information and operations.
- Analyze the effect of standard contracts on knowledge transfer between phases/actors and disciplines.
- Proposals for adjustments and/or additions to existing contractual models to enable optimal operation.

Implementation of the project

The project builds cumulative knowledge, i.e. the project builds on the knowledge developed in previous studies with a clear relation to KTH Live-In-Lab and HSB Living Lab.

Participating researchers in the implementation are Jonas Anund Vogel (JAV) (PhD in energy systems, director of KTH Live-In Lab and head of research and development at Bengt Dahlgren), Tina Karrbom Gustavsson (TKG) (PhD in industrial economics, professor of project communication) and Cyril Holm (CH) (PhD and lecturer in general law).

The research group complements each other in terms of knowledge and experience in construction, property management, optimization of e.g. energy systems, organization of collaboration and laws and regulations.

What's next?

In 2022, 10 new projects started covering a wide spectrum of interdisciplinary research. Several of the new projects have as a key element the active participation of students. Projects with goals such as social sustainability will map students' behavior and create a change pathway for sustainability transformations.

The HiSS LiL Social Case Study – Social interactions and sustainable lifestyle

The research team have the ambition to develop a new research area in urban development (studies). Wellbeing in smart cities is the defined research area, focusing on interactions of human-machine-computers or "cyber-physical-human systems", based on human decision making on an institutional, individual and neurological abstraction level. The smart cities of the future is our main application area as these are complex cyber-physical-human systems. The project will develop a framework for capturing interactions and dynamics in these systems and demonstrate the applications in user case studies.

Sponsored by Digital Futures, HiSS represents a highly multi-disciplinary research effort ranging over three schools at KTH: the School of Electrical Engineering and Computer Science (EECS, KTH), the School of Industrial Engineering and Management (ITM, KTH) and the School of Architecture and the Built Environment (ABE, KTH).

The preliminary phase of this experimental study will be conducted at the Live-in-Lab (LiL) Testbed KTH and the occupants of the Live-in-Lab Testbed KTH will be asked to be involved for a time period spanning approximately 5 weeks. Aim is to test the general methodology and tools, and assess them through feedback from the participants.

Before the experiment, a pre-survey will be sent to the participants to understand their habits and how they perceive the environmental impact of their lifestyle; the aim is to obtain a reference state, that can later be used to analyze if and how we change our behavior. During the experiment, the participants will be asked to compile weekly self- reported surveys (~10-15 min/week) and to interact with each other. Moreover, measurements from sensors at apartment level will be collected to understand the participants' household consumption. After the experiment, an additional survey will be sent to the participants, whose purpose is to obtain feedback on the methodologies used.

Read more about the project:
https://www.hiss-digitalfutures.se/home

Sound for Energy – Sonic interaction design to support energy efficiency behavior in the household

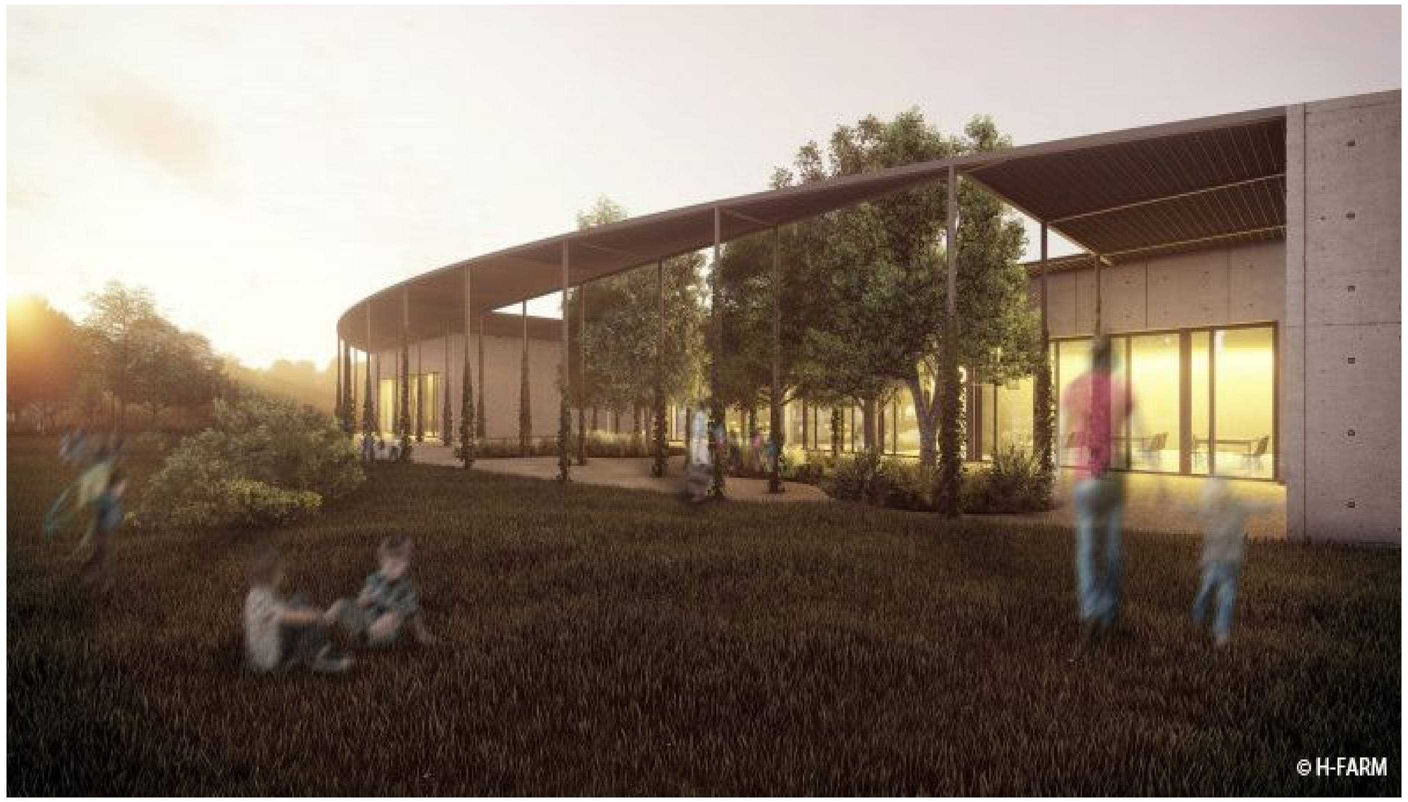
Energy provides heating, lighting and more, but it affects the environment. In Europe, households account for 25% of the energy-related greenhouse gas emissions. Residential energy feedback could contribute to 5%–10% energy consumption reduction, but there are several barriers including those related to user behaviour. Visualisations of energy costs and savings are not enough: interventions must be tailored, frequent and engaging.

Our novel approach will employ sound. We will design, develop and evaluate real-time digital sonic interactions as augmentations of individual appliances and aggregated smart meters' outputs, which will promote energy efficiency in the household. Without adding to the myriad of "beeps" in our life, we will create new everyday sounds meant to be felt, implicitly understood, rather than listened to.

Our procedural audio models, which can be embedded and personalized, will be based on our research on sound, interaction design, behavior change, and energy. The project benefits from access to high-resolution energy data of the KTH Live-in Lab and its individual and shared spaces for testing.

Read more about the project and find the papers:
https://www.soundforenergy.net/about

Sound for Energy



H+Forest

Project leader: Misse Wester (Lunds universitet)

Partners in project: Lunds universitet, KTH, SustainLab, Arkitekturinstitutet, Boiler AB och Tekniska museet, Volvo Cars, Akademiska Hus

Project H+Forest will develop knowledge about sustainable lifestyles and behaviors. The project takes its starting point in the needs and behaviors of the younger generation in order to create sustainable habits and establish a learning process in everyday life. The project involves collaboration between students, researchers, and designers to develop knowledge about behaviors in order to better understand people's actual behavior within the built environment. The goal is not only to reduce energy and material consumption but also to achieve social and ecological benefits, creating a more sustainable and inclusive living environment.

The project focuses on the campus of the future, where housing and learning environments become more diverse and shaped by how students live and learn. The project will develop a prototype of what such a future living and learning environment could look like. The prototype will be designed in collaboration with young people aged 16 to 25 and tested at two campuses, Lund University and KTH, and implemented in Akademiska Hus's ongoing work to improve campus energy efficiency (Effektivt Campus). Here, a prototype of concepts for future living and learning physical spaces will be created to inspire and help us generate new ideas and habits.

The project will also establish universal goals for sustainable behaviors, called "Sustainable Behavior Goals" (SBGs), which can be compared to the global sustainability goals (SDGs) that are part of the UN's climate objectives. In the "Sustainable Behavior Goals," different types of behavior will be classified to better illustrate the climate impact of various behaviors. These goals will also be applicable outside of this project.

The "H" in the project name stands for "Human," and "Forest" symbolizes a nature-based mindset with nature-inspired processes and design.

Read more about project:
https://designforenergi.se/portfolio/hforest-samproducerad-kunskap-kring-den-hallbara-framtiden/

Impact & Outreach

Building pathways for sustainability transformations

Impact & Outreach

KTH Live-In Lab functions as a collaboration platform and infrastructure, generating both knowledge, results and commitment.

Examples of KTH Live-In Lab's impact and outreach during 2022:

- KTH Live-In Lab due to its pioneering work hosted the Swedish Minister of Education and the EU Commission starting an important dialogue on sustainability.
- KTH Live-In Lab has supported and played an important role in the start-up of Lund University Living Lab, discussions concerning a possible "Uppsala Living Lab".
- KTH Live-In Lab's concept of testing and sharing results and data has been presented in national TV, radio, industry press such as Kyla & Värme, Energi & Miljö, Byggindustrin, and Fastighetstidningen.
- Representatives from KTH Live-In Lab were involved in the development of the coming building codes, "Möjligheternas byggregler", focusing on how to enable innovation.
- KTH Live-In Lab is a test bed in ERA-Net Smart Energy Systems: eranet-smart-energysystems.eu/ll/708/preview.html
- KTH Live-In Lab is actively collecting and sharing data from the test beds and projects carried out within the framework of KTH Live-In Lab. KTH Live-In Lab's database (or Datapool) is used by researchers, collaborators, teachers and students. Many degree projects and courses have used data regarding everything from ventilation and water studies to cyber security and user behavior.
- Through research projects, KTH Live-In lab has contributed to three buildings, containing 305 student apartments on KTH Campus, built as plus energy buildings.

Key performance indicators

In 2022 KTH Live-In Lab has developed according to the business plan and established Key Performance Indicators (KPI). KTH Live-In Lab has decided on three focus areas: Methods for knowledge transfer, Value-creating data from buildings and education connected to KTH Live-In Lab. Results from all three areas are used in the daily operations of KTH Live-In Lab.

KTH Live-In Lab's method for knowledge transfer

Develop methods for knowledge transfer from project activities to society. In this project, two processes have been developed: the project process and the dissemination of knowledge and impact. Commitment and knowledge are partly linked to the project participants, which is why a model for trust and collaboration has been developed and a model for disseminating so-called implicit knowledge.

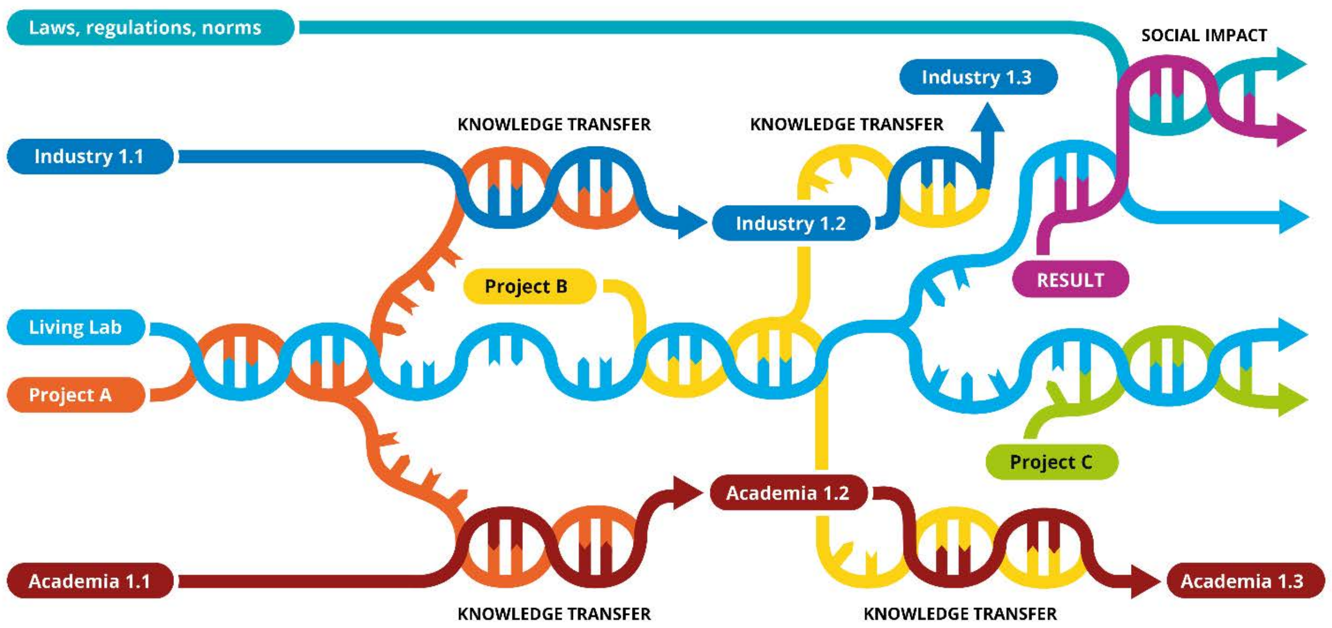
It is of utmost importance that the project members' knowledge from collaboration as well as from project implementation is managed and followed up to ensure that it is disseminated within the organizations. Further collaboration, joint activities and follow-up studies lead to societal change and real impact.

Value making data from buildings

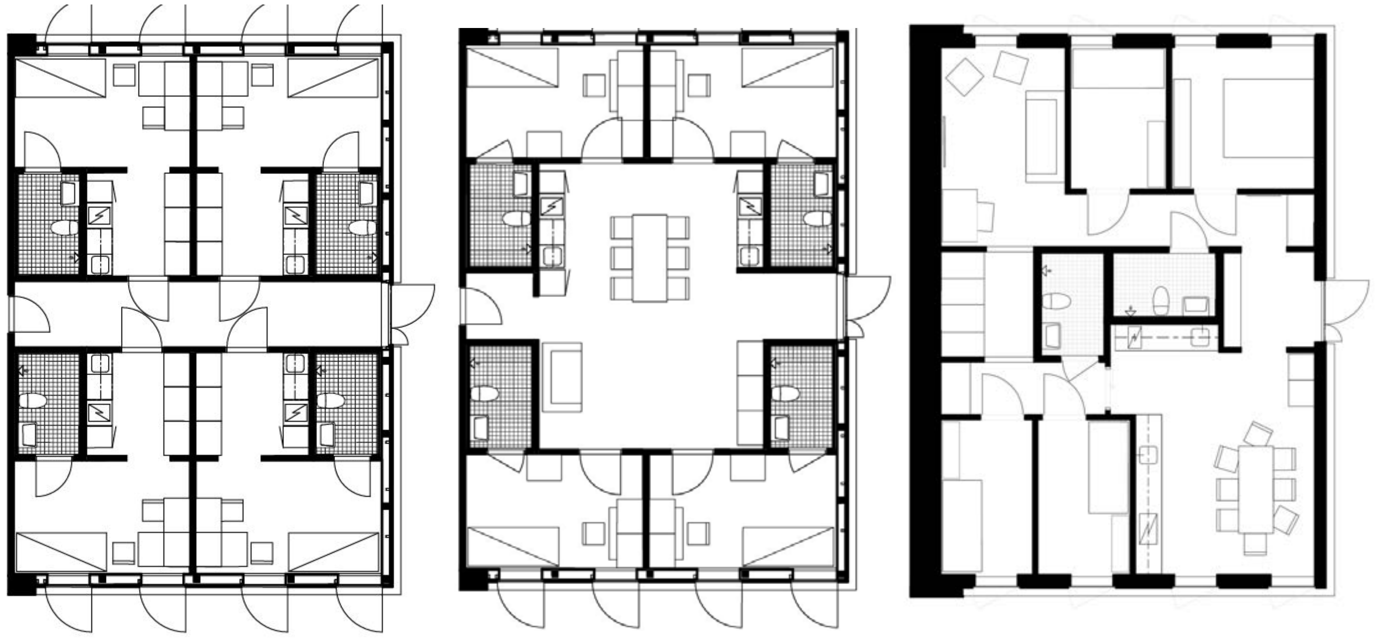
KTH Live-In Lab collects data from testbeds, so called 'trusted buildings', and from completed projects and makes this data available to researchers and students. KTH Live-In Lab also ensures that the data made available is in accordance with current rules and laws, such as GDPR. The work revolving around data management has been carried out in collaboration with the center partners Schneider Electric and Akademiska Hus, as well as partly in collaboration with KTH IT, Stockholm University and HSB Living Lab. The work has been partially financed by Digitaliseringsplattformen. The work has resulted in KTH Live-In Lab being able to collect and make data available. Aspects such as GDPR and ethics reviews have been investigated by two consecutive research projects funded by Smart Built Environment.

Education 2022

The focus of this project lies on developing an education operation linked to the project operation and the utilization of knowledge. This project has resulted in proposals for the design of future education linked to KTH Live-In Lab, and several ongoing and completed activities such as week-long case studies in collaboration with the industry.



Knowledge transfer and impact in the form of DNA and m-RNA in relation to KTH Live-in Lab.



The evolution of the Testbed KTH: Testbed 1.0 (left image), Testbed 2.0 (middle image), Testbed 3.0 (right image)

KPI - Research

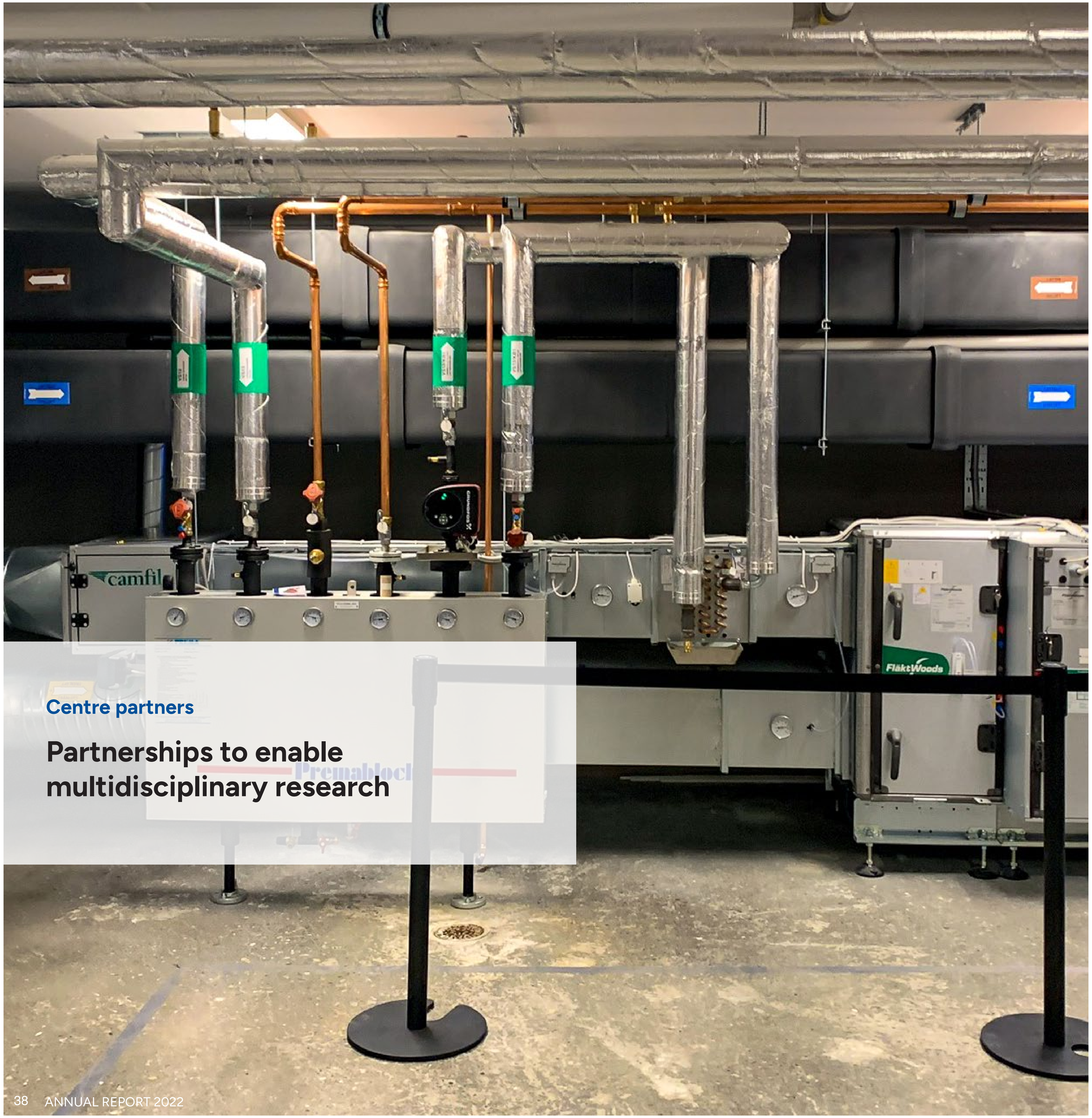
Table 3 – Research targets and results of KTH Live-In Lab for 2021 – 2022

KPI	Target 2021	Results 2021	Target 2022	Results 2022
Number of ongoing projects	10	16	12	16
Number of new projects	6	5	6	10
Number of projects initiated by the KTH LIL management group	1	3	4	5
School-wide project collaboration	50%	56%	50%	56%
Number of spin-off projects	1	3	6	6

KPI – Impact and Communication

Table 4 – Impact and communication targets and results of KTH Live-In Lab for 2021 – 2022

KPI	Target 2021	Results 2021	Target 2022	Results 2022
Public presentations (discussion articles, newsletters, communication activities, study / site visits)	10	15	15	48
Seminars and Workshops	6	10	6	3



Centre partners

Partnerships to enable multidisciplinary research

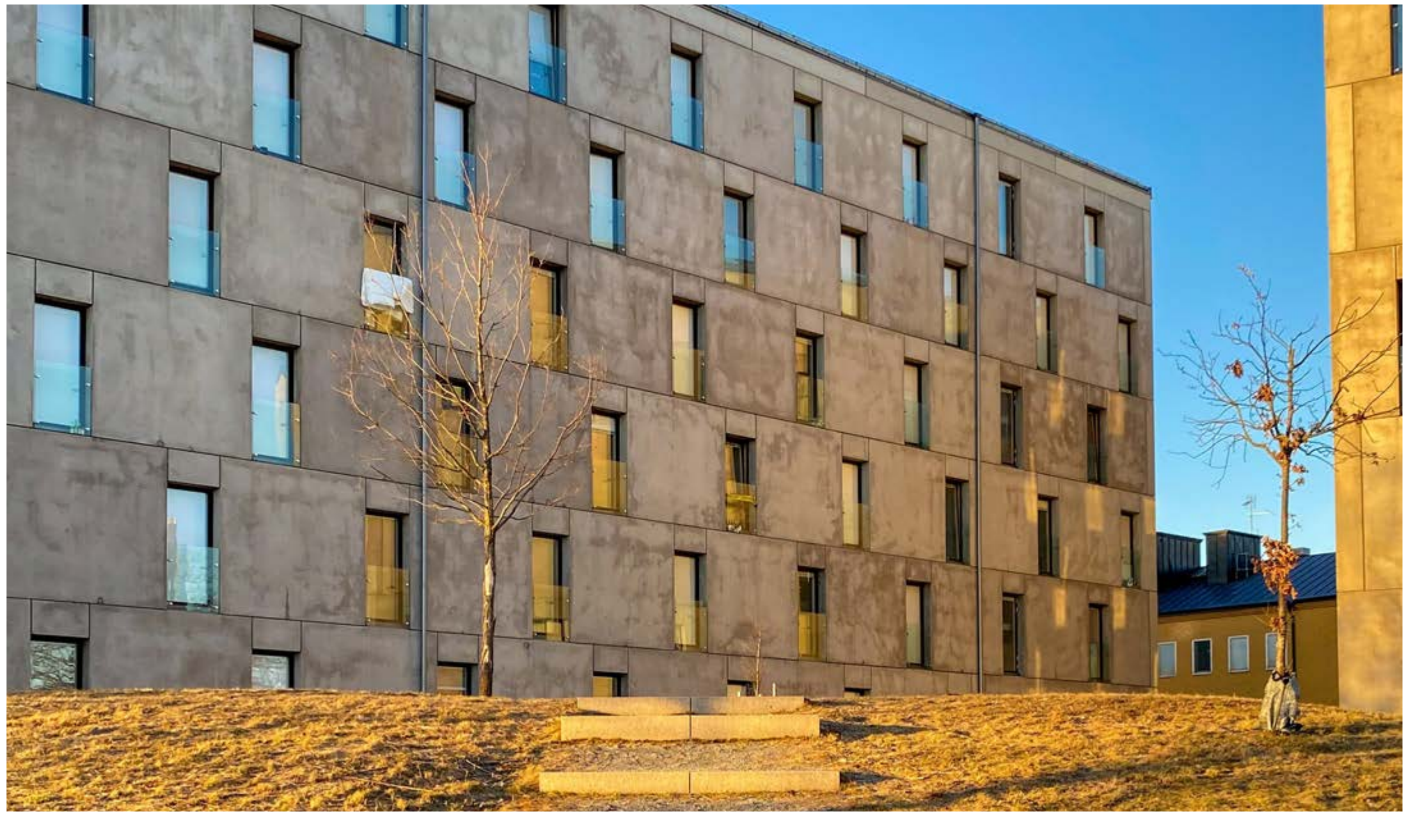
Partners

Since 2019 KTH Live-In Lab has become a competence center with four partners: Einar Mattson, Akademiska Hus, Schneider Electric and Bengt Dahlgren. All these years KTH Live-In Lab has developed projects with 150+ partners establishing collaborations between academia and industry.

KTH Live-In Lab as a competence center has 4 central partners (Einar Mattson, Akademiska Hus, Schneider Electric and Bengt Dahlgren) and 29 partners for the ongoing projects.

Project Partners 2022

- KTH
- Thermia
- ToM Energy Consulting Company
- Unige
- Sindeq borrteknik AB
- Rototec
- Asplan Viak
- Dandelion
- NIBE
- HP
- Nowab
- Wilo
- Digitalisation platform
- KTH Sustainability
- Ericsson
- NOWAB
- ETM Kylteknik
- SISAB
- KTH ITM
- KTH ABE
- Umea University
- Chalmers University of Technology
- Lund University
- Charles Strand Design AB
- KTH Digital Futures
- KTH EECS
- KTH Media Technology and Interaction Design
- KTH Green Leap
- Stockholm University



Einar Mattsson

On the KTH Campus, Einar Mattsson has built 305 high-quality student housing units totaling 6,329 square meters. These include the KTH Live-in Lab testbed, built in collaboration with KTH with Einar Mattsson as the main financier.

The units are rented to KTH and owned and managed by Einar Mattsson. The first students moved in in September 2017. KTH Campus plays an important part in the city of science, together with Stockholm University and Karolinska Institutet. Nature and green spaces are prominent parts of the area's character, including a steep slope with visible hills and mountains.

The design of the three detached buildings, which are located at KTH's highest point, was inspired by this natural setting. The houses, designed by Semrén and Månson, have a smooth concrete facade with French glass balconies that can be likened to sculptural stone blocks. They are built of solid materials for long-term durability. The boundary between the landscape and the built environment is important and sharp.

Outdoors, simple but powerful materials are used that relate to the materiality and feel of the buildings. Meeting places, in the form of a common bicycle room, a large laundry room with a study area and the common post room, have large windows to create safer outdoor environments.

The houses constitute a 'plus energy' property, which is made possible by, among other things, waste heat exchangers, geothermal heating and solar panels on the roofs. Einar Mattsson is a long-term property owner who sees the investment on the KTH Campus and the KTH Live-in Lab as an investment in creating an attractive and sustainable city.

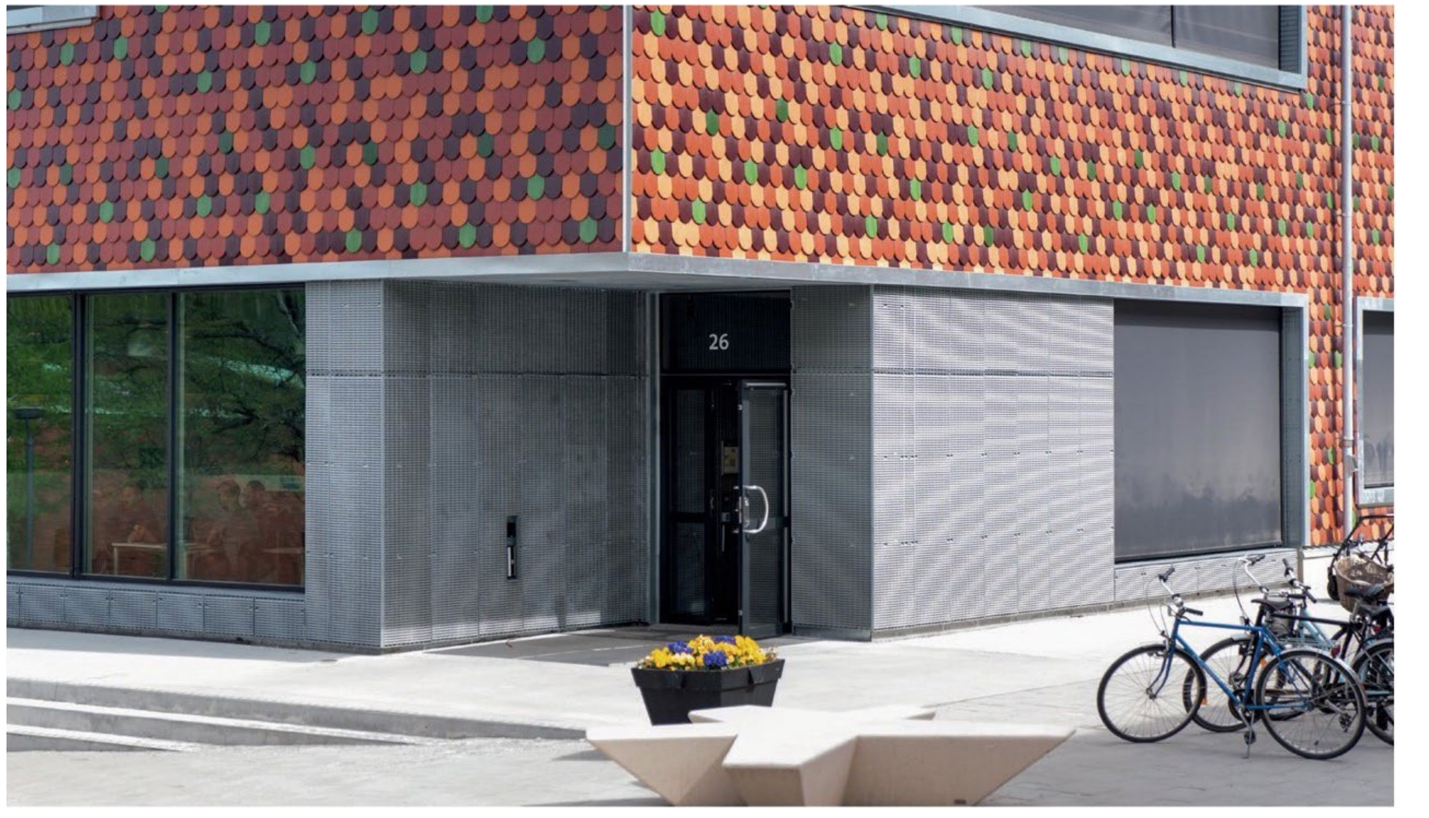
The Einar Mattsson Testbed

The building:

- Built in 2016-2018
- 305 apartments
- 10 590 m2 (Atemp)
- Concrete exterior wall elements
- Outer wall: 0.11 W/(m2*K)
- Windows: 0.64- W/(m2*K)

The energy system:

- 3 heat pumps x 60kW
- 667 solar panels
- 4+1 ventilation units (FTX)
- Geothermal heating, 12 bore holes, 3 185 meters
- 315 Building Controller Transmitters (BCT) for smart management of technical systems



Akademiska Hus

Akademiska Hus has built 230 student apartments at Teknikringen on the KTH Campus in Stockholm, with room for more than 400 students. The need for student housing in Stockholm is strong, and housing availability is crucial for the city's future attractiveness.

Akademiska Hus provides the Teaching House at the KTH Campus as a testbed to enable testing and research in collaboration with KTH Live-In Lab.

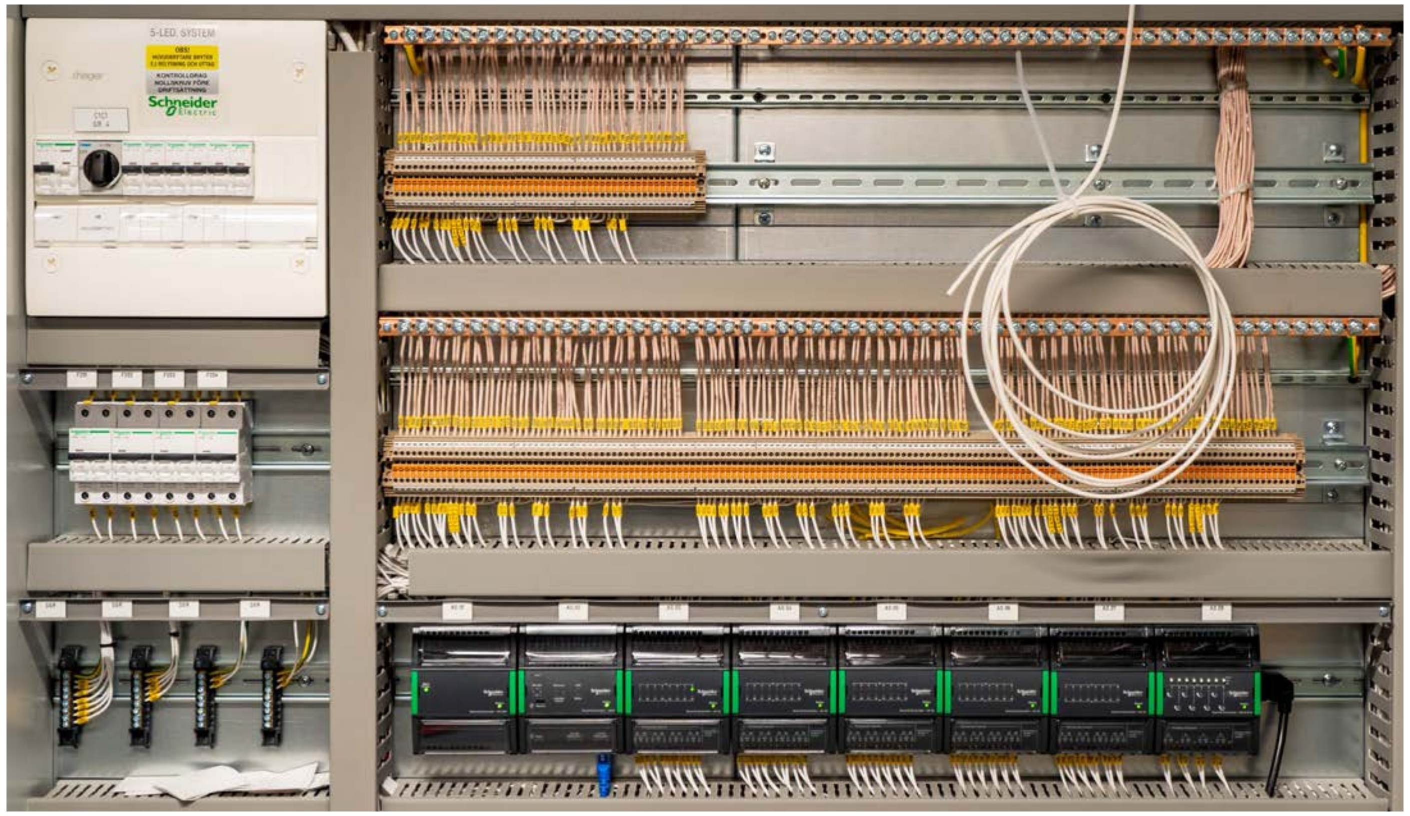
More housing contributes to a more vibrant campus as people are present, living their lives at all hours of the day, something that both Akademiska Hus and KTH strive for.

The engagement of Akademiska Hus in KTH Live-In Lab aims to make it possible for new competitive, environmentally sound and sustainable products and services to reach the market more quickly, in the end resulting in smart and sustainable buildings and campus areas.

Akademiska Hus, together with Einar Mattsson, Schneider Electric, and Bengt Dahlgren cooperated with KTH to enable an increase in the number of testbeds within KTH Live-In Lab. Also, to ensure impact from the research being performed at KTH and other universities. The sand-boxing methodology, going from ideas to physical installations within years instead of decades is Akademiska Hus way to solve problems for the future.

The Akademiska Hus Testbed

- Inaugurated October 2017
- Total area about 3500 m2
- Designed according to the wishes of teachers and students
- Educational tool for aspiring architects and community builders
- 363 study places + 6 exercise rooms + 11 group rooms & break-out areas
- Undervisningshuset is built according to the environmental certification Miljöbyggnad Guld, which is the highest ranking (Gold, Silver, Bronze).



Schneider Electric

Schneider Electric wants to contribute to a more innovative construction sector and therefore deepened its cooperation with KTH Live-In Lab in 2019. Schneider Electric will actively participate in research and development at KTH Live-In Lab for three years through consulting, services, and technology.

'With an increasing world population, digitalization and increased energy use, especially in buildings, the demand for innovation and sustainable solutions for buildings is greater than ever,' says Andreas Finnstedt, Vice President, and Head of the Digital Energy business area at Schneider Electric. 'We need to collaborate and together create solutions for sustainable buildings and cities that utilize our resources in a smart way.'

'Our ambition is to contribute to this development and create tomorrow's buildings and projects that can meet new demands and needs. The KTH Live-In Lab is an opportunity for us at Schneider Electric to test new solutions, products and services that contribute to more sustainable development.'

So far, Schneider Electric has installed smart home solutions. The installations are monitored and optimized and can be adapted by property owners, partners, and residents.

Schneider Electric at KTH Live-In Lab

Schneider Electric tests new solutions, products and services at KTH Live-In Lab.

So far they have installed:

- Smart home solutions (Wiser Energy, KNX)
- IoT platform EcoStruxure TM Buildings Operation
- Connected security system Security Expert
- Electric car charger EVlink

Bengt Dahlgren

The technology consulting company Bengt Dahlgren wanted to contribute to a more sustainable and innovative construction sector and therefore joined KTH Live-In Lab as a center partner in 2021.

Bengt Dahlgren provides KTH Live-In Lab with knowledge about among other things, digitalisation, and digital twins. A key activity and area where Bengt Dahlgren's competence as a technology consultant is of the utmost importance is the development of Testbed X – a virtual Testbed made to enable research into the potential of digitalisation for the design, production, and management of smart and sustainable buildings.

The digitalisation of the construction sector is one of the major challenges the industry is currently facing. A digital test bed will enable the necessary development of tools for planning, production, and operation of smart and sustainable buildings. At the same time, the test bed will be a neutral platform where various universities and companies can test and develop the systems and services of the future for smart and sustainable buildings and cities,' says Jonas Anund Vogel, director of KTH Live-In Lab.

For Bengt Dahlgren, this means that the company will invest in research and development at KTH Live-In Lab during a three-year period through consulting, services, technology and more.

'Research and development are an important part of Bengt Dahlgren's work and permeate our entire business. It therefore feels very exciting and important for us to expand the collaboration with KTH and contribute with our knowledge within KTH Live-In Lab, and thereby enable future systems and services for a sustainable society,' says Erik Bolander, CEO of Bengt Dahlgren Stockholm AB.

The Bengt Dahlgren testbed

Bengt Dahlgren's collaboration with KTH Live-In Lab will run from 2022 to 2024. Bengt Dahlgren plays an important part in the development of KTH Live-In Lab's new, digital testbed: Testbed X.

Bengt Dahlgren operates in the public construction sector and works with installation, fire and risk, construction, real estate, energy and the environment.

Thank you all for the great year!

Get our newsletter

For updates on current and upcoming projects, seminars and more, sign up for the KTH Live-In Lab newsletter:
kth.se/en/2.88186/nyheter/nyhetsbrev-1.894666

Contact

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