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Rotatable Smart TinyLab, a platform for testing integrated façades and indoor climate

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Rotatable Smart TinyLab, a platform for testing integrated façades and indoor climate

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Abstract. The new Smart TinyLab (STL) for system integration in the building industry is a lab where building partners and construction-related companies can develop, test, validate and demonstrate their products in practice to be as energy-efficient as possible to contribute to formulated CO2 emission reduction targets. STL is located near the Saxion University of Applied Sciences in Enschede and has been operationalized since the spring of 2021. In the lab, one can simulate and assess quantitatively the effect of building products, HVAC components, smart technologies, user-related aspects and the outdoor climate on energy consumption and indoor climate conditions. The lab allows the comparison between theoretical and practical characteristics and energy consumption figures. Together with partners from the construction industry, innovative products, devices and systems in a simulation and field test environment have been tested and validated. During STL's start-up phase other tiny twin-labs with outdoor setups in Europe were compared. Turning the lab in its entirety to face or be averted from direct sunlight makes STL rather unique in its kind.

1. Introduction
The new Smart Tiny Lab at Saxion Enschede (2021) has two test chambers (15.7 m^2) plus an installation room (15.5 m^2). The aim is to test techniques in this new lab that contribute to the buildings' energy transition and circularity and improve indoor climate conditions. The focus is on innovations in prototype and pilot implementation in TRL levels 5-8, i.e. still in the pre-certification stage. In STL companies can test new market innovations in the field of energy management and control in conjunction with other systems and solutions. As a result, we avoid sub-optimal performance and contribute to cost-effective solutions that contribute to CO_2 goals. By integrating multiple systems within one test environment, an integrated performance assessment of a solution in the larger framework has been achieved by integrality and interactivity. Furthermore, students can carry out research assignments in the lab and are thus introduced to various building physics quality assessment methods in practice. Three outer facades of the test chambers are demountable and replaceable and the indoor climate is adjustable. The entire lab is rotatable on a steel rotating platform. Tracking the solar's azimuth angle enables to perform measurements toward or averted from direct sunlight. This concept makes the STL rather unique in its kind.

1.1. Background
Innovation in the building industry is needed to deploy new efficient technologies and services that contribute to the government's climate and circularity targets and improve the indoor climate. The

challenge is to find solutions that are economically sound and can be applied on a large scale. The construction of new houses must be at a higher rate, cheaper, more energy-efficient and more circular, for example with biobased materials, improved thermal comfort and a better indoor climate. The same applies to energy improvements and high-level renovations of the existing building stock. Many construction companies and manufacturers are located in the eastern of the Netherlands, but local test facilities were lacking with respect to energy innovations in building practice. In the area of integrated concepts and sophisticated smart control technologies that respond to the individual needs of residents, there is still much to improve and save on energy and costs. There is still great development potential concerning prefab and modular construction, industrialized production methods, smart building-user interaction, exploration of material properties and emission (health effects) of new building materials and constructions from new materials, recycled raw materials and bio-based materials. Enschede's new STL allows the testing of new concepts in practice under field conditions.

Figure 1. Smart TinyLab Enschede

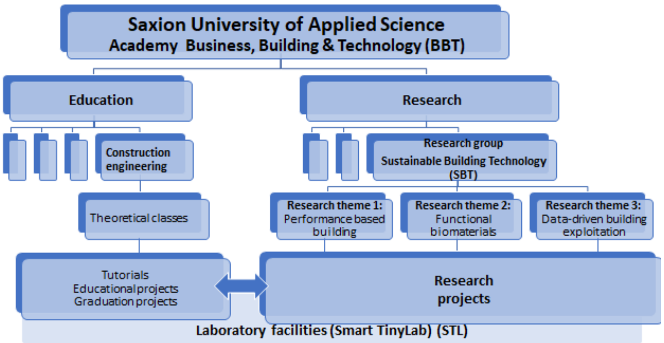

Figure 2. STL's role in education and research

1.2. Preventing failure costs through testing and validation

The development and application of innovations in building practice are far from risk-free. Mismatch from design elements to an integrated total system regularly leads to unexpected problems when multiple disciplines are involved. Often problems become apparent during production, storage, transport, and application at the building site or in the usage phase. Testing system-integrated façade elements in a practical setting enable timely adjustments at an early stage to avoid unnecessary failure costs.

1.3. Focusing on innovations in prototype and pilot implementation

Companies can test market innovations in the field of energy management and control in the lab in conjunction with other systems and solutions. STL focuses on innovations in prototype and pilot execution in TRL levels 5-8, still in the pre-certification stage. The lab is extensively equipped with sensors to perform various measurements and quantify integrated system performance. Both short-term and long-term measurements are possible. This gives companies input for further development, practical applicability and future product certification.

2. Why measure under field conditions

More attention is being paid to the quality assessment of buildings during design and in practice during the building process. This is partly the result of a new Dutch building Act, the Wet Kwaliteitsborging (the Quality Assurance Act for Construction), that requires contractors to ensure quality during the construction process of new buildings. This requires tracking and tracing of buildings' performances. Contractors are responsible if the requirements of the Dutch Building Decree or issued guarantees are not met. Grey areas arise when manufacturers provide guarantees on a product, but this does not count for its correct application or proper functioning of the total system. Thus, practical testing is important for innovative solutions to determine the proper functioning of the total system. From the 2021-2022 academic year, architecture students carried out research assignments in the Smart Tiny Lab. They have been introduced to applicable quality assessment methods, to be prepared for quality assessment in their future practice.

3. State-of-the-art small lab environments in Europe

There are various small lab environments nationally and abroad for energy and indoor climate tests that are comparable in size to STL. Some of these have an outdoor set-up real environment and are often focused on testing certain innovative techniques in houses, such as smart technology. Examples are Homelab Gent [1], Green Village Delft [2], iHomeLab Luzern [3], Casa1.0 Eindhoven [4], Selficient Utrecht [5]. Other labs test focus on specific performances of (renovated) buildings or building components or indoor climate, such as Energy House Labs Salford [6] and Heat House Hanzehogeschool Groningen [7]. Most of these labs are situated in the open space outdoor such as Energy House Salford which simulates the outside climate in a controlled lab environment. Unique are the identical Passys Test Cells [8], situated at several locations in Europe during the 80s. They were constructed to validate thermal calculation models in practice. Simulation of real living environments was not intended.

In the preliminary design phase of the STL, SBT (Sustainable Building Technology Research Group) researched several tiny labs in Europe with a twin set-up and identified at least four outdoor tiny labs. Only a limited number of the small laboratories are equipped to perform "twin measurements", i.e. simultaneous control measurements, and are facilitated with replaceable façade elements for research and installations. In Europe, the Twin House Munich [9], Test Cells Seville [10], and MateLab Cambridge [11], in addition to the STL, adhere to this standard (see Table 1). In addition we found twin outdoor test cells Demona EPFL Lausanne [12], Cells EPFL Freibourg [13] and Lobster Kit Karlsruhe [14]. It is concluded that among these only Lobster Kit Karlsruhe is rotatable. Therefore the STL occupies a unique position among these Twin Labs that were set up outside because of the ability to run the lab in its entirety along with the sun's azimuth. Below is a brief overview of four outdoor twin test environments and more in-depth information about STL.

Twin House (Munich, Germany, 1980) [9] Fraunhofer's Twin House project (1980) consists of two identical (real) dwellings (82 m^2 floor area) in the open air. Six rooms are on the ground floor and two in the attic under the 30° roof with orientations north and south. The identical built single-family houses enable the comparison of performances of different building concepts and heating systems under identical outside climate conditions. The set-up of these houses enables the comparison of results of different energy and comfort scenarios in two identical houses and was also used in IEA-Annex 58 to validate building simulation programs. They comply with current German regulations. Radiators and underfloor heating combined with a gas condensing boiler provide heating. Demand-based ventilation, as well as ventilation with heat recovery, are options. The twin houses are extensively equipped with sensors, data acquisition and monitoring equipment. Measurement results can be monitored remotely. Research with these twin houses focuses on the energy efficiency of new house concepts, passive solar techniques, thermal insulation techniques of roofs and facades, heating systems, ventilation systems, intelligent control concepts in smart grids, sun-shading devices, etc. Exterior components are changeable, likewise layout and heating and ventilation installations on the ground floor. For specific research purposes, adiabatic separation of individual sections is an option.

Test cells Seville (Seville, 2017) [10] Two separated modules, with two identical test cells of 2.4×3.2 m^2, are located at the area of the University of Seville in an outdoor setting. The separated test cells imitate a housing space. The purpose of the test cells is to evaluate the energy performance of facades, comparing the performance of two different configurations. Each module is north-south oriented and consists of two experimental test cells with a customizable façade for research purposes (2×north, 2×south). The two test cells in one module are separated by an installation zone. Mirroring two modules allows simultaneous assessment of the performance of a solution and a reference under equal outdoor conditions.

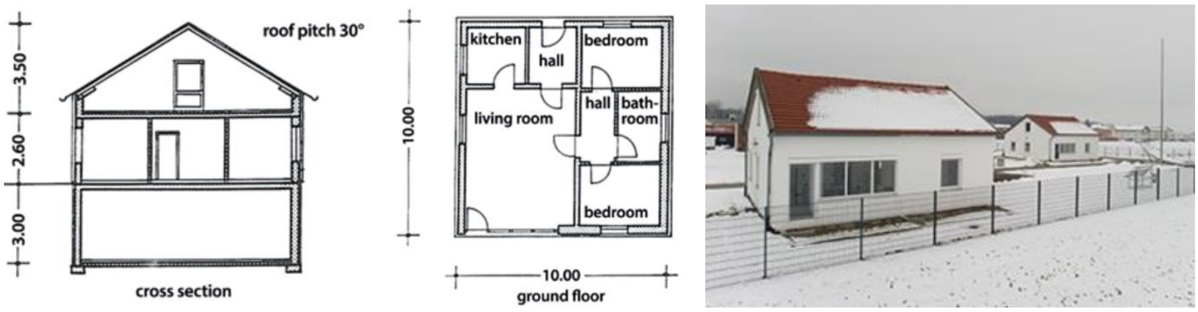

Figure 3. Twin Houses Munich, Cross-section, ground floor and picture [9]

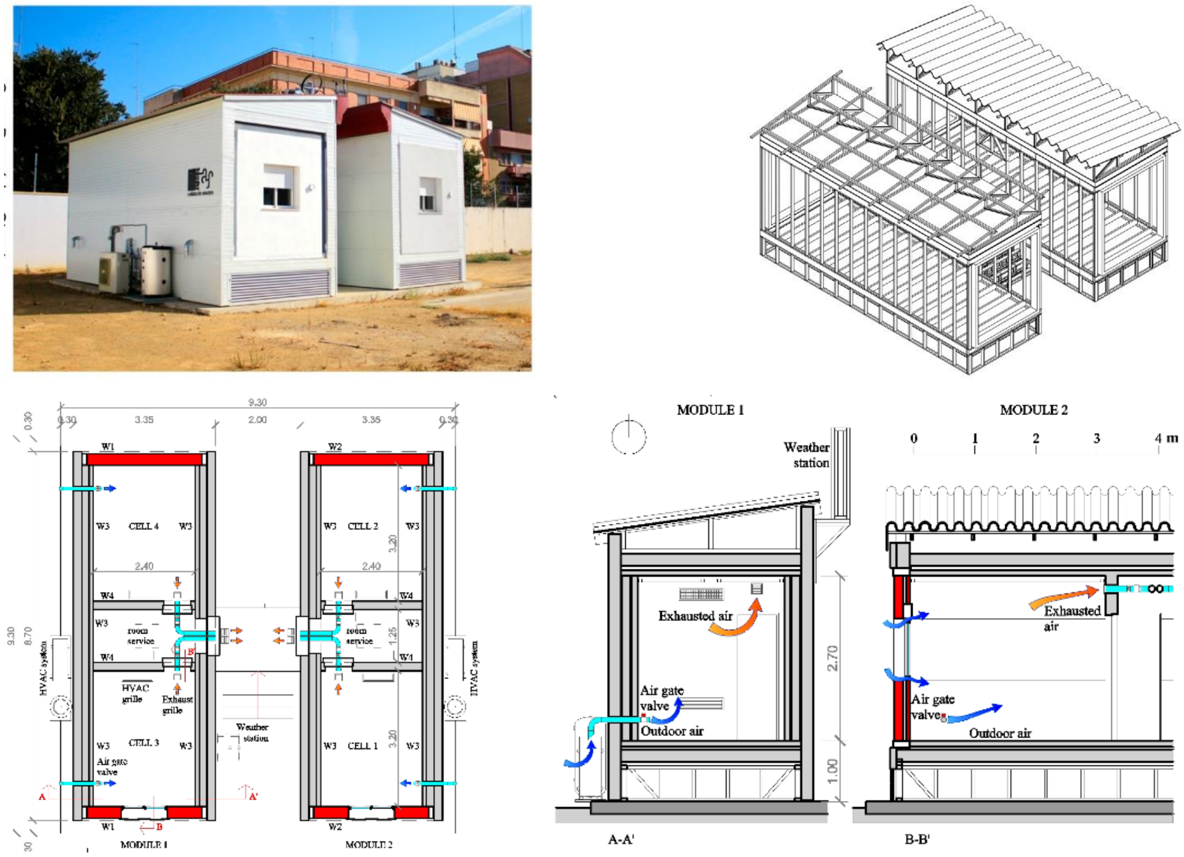

Figure 4. Picture of Test Cells Seville, timber construction, ground floor and cross-section [10]

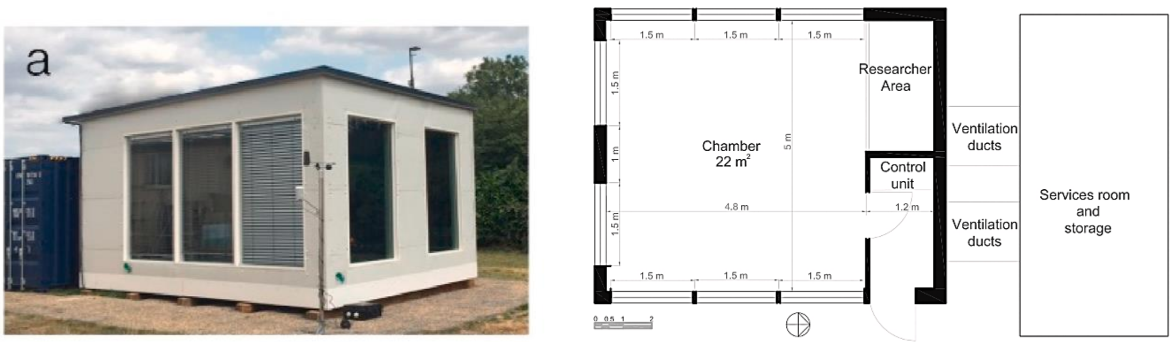

Figure 5. Picture of MateLab Cambridge and ground floor section [11]

A mix of measures eliminates thermal influences from outside as much as possible. The 9.30 m module is set up with 10 cm solid concrete surrounded by a steel frame for the attachment of facade and roof panels. Corrugated steel sheets cover the roof. The low U-values of outer walls, floor and ceiling are 0.05 W/m^{2}K. The white finish reduces adverse effects on the indoor climate. There are two identical HVAC systems (187 m^3/h). Several sensors record the power consumed, electricity use, voltage, air velocity and temperature in the ventilation ducts, water temperature in the heat pump (supply and return), and flow meters in the air conditioning units. Multiparametric sensors measure environmental and energy variables. Logged data is temporarily stored and then transmitted to the University of Seville's network.

MATELab (Cambridge, 2018) [11] By testing the user's influence on innovative and dynamic smart techniques, the individual comfort and well-being of users can be improved. The main purpose of Cambridge's Mobile Adaptive Technology Experimental Lab is to research human reactions to the indoor climate with different types of facades in a realistic environment. The lab aims to bridge the gap between conventional accurate, but often unrealistic, laboratory measurements and realistic, but not well-controlled measurements in real offices. The lab is a solitary 35 m^2 open-plan office. It can be separated by a wall into two identical rooms for twin- or control measurements. Eight full-height removable facade panels (2× in South, 3× in East, 3× in West facades) have partial or full-height glazing. Wooden frames in three facades are customizable. The lab cabin can be moved in its entirety to another orientation by lifting and turning. Outer parts are well insulated: U-façade: 0.20 W/m^{2}K, U-roof: 0.159 W/m^{2}K and U-floor: 0.20 W/m^{2}K. The internal floor is 0.90 m raised from the ground. With various types of sensors, the indoor climate and reaction of the body and occupant's interaction are well monitored in conjunction with indoor and outdoor climate conditions.

Smart Tiny Lab (Enschede, 2021). Two mirrored, fully air-conditioned test cells - with dimensions 3.6×4.8×2.9 m^2 comparable to an office room – are prominently located at the Saxion University of Applied Science in Enschede in a rotatable outdoor arrangement. Energy loss and indoor climate measurements are the main objectives. The rotating laboratory enables measurements at different orientations. Tracking the solar azimuth angle enables the execution of measurements toward or averted from direct sunlight. Two outer wall parts in each test cell are customizable. Monitoring equipment for registering temperature and/or humidity for a long period can be fixed in/on the façade panels. A concrete roof contributes to a stable indoor climate. The partition wall between the rooms is demountable. The setup allows the lab to be converted into a large hotbox to determine the heat transmission through the wall by creating a temperature difference between the two test spaces. Important factors are: (a) the indoor climate is adjustable in the test spaces on both sides of the wall, (b) the partitioning wall between the rooms is demountable and replaceable and (c) the test spaces are thermally uncoupled. STL meets these criteria. The indoor climate of STL is controlled. The desired air temperature and humidity can be set per room. Sensors are built into the suspended ceiling. The room is heated or cooled via the air and the floor heating. A heat pump provides the energy. Smart control technology is used to adjust the climate and simulate fictitious resident behaviour. The required heating and cooling for both rooms are generated by a single heat pump with a buffer.

There are four means of heating/cooling the test rooms: (a) using the underfloor heating system (b) using the HVAC system (c) test facility: using one of the four radiator connection points available per room (inlet and outlet per point) to test radiators or other compatible devices and (d) test facility: Heated glass pane. Methods (a) to (c) utilize the heat pump and method (d) uses electrical energy. An Air handling unit (AHU) with integrated heat-recovery is utilized to ventilate both rooms. Per room, humidity, CO_2 levels, temperature, inlet volume and outlet volume can be individually controlled by a series of control valves and steam generators. Lighting (on/off) is controlled by movement. Sensors are linked to a data acquisition system. Measurement results can be read out and processed remotely. The STL features a wide range of measuring instruments, such as a PMV measurement set, temperature sensors, CO_2, VOC and fine dust measurements that are linked to a data acquisition system to store and

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process the data. Because the climate in the test rooms can be controlled, the STL is also suitable for indoor climate research with test subjects or with measuring instruments. BRControls supplies the measurement & control technology for the mechanical installations in the two test labs in close collaboration with Winkels. For the primary installations, BRControls supplies its BRC-46 system line complete with the BRT-24 room control devices and the BRT-35 multifunctional ceiling sensors.

Table 1. Comparison of four outdoor twin test facilities in Europe

Name twin-lab Location/ Year		Twin Houses [9] Munich, 1980	Test Cells [10] Seville, 2017	Mate-Lab [11] Cambridge, 2018	Smart TinyLab Enschede, 2021
Use	Main research topic	Energy/ indoor climate	energy / indoor climate	indoor climate / human response	energy / indoor climate
	Main research elements	facade/ installation	facade/ installation	facade/ installation	facade/ installation
	Number of modules	2 (houses)	2 modules (4 test cells)	1 module (1 or 2 test cells)	1 module (2 test cells)
	Rooms per module	6 + 2 (attic)	2	2	2
Site	Orientation	North-south	North-south	movable (pick up)	Rotatable (instant / sun tracking)
Room	Modular room	no	yes	yes	yes
	Room combination	yes	no	yes	yes
	Customizable façade elements and dimension elements	yes (test rooms ground floor)	yes per test room: $3{\times}2.7$ m^2	yes 8 full height panels (W=1.5 m each) (2×S, 3×E, 3×W)	yes per test room: $2.9{\times}2.6$ m^2 and $4.1{\times}2.6$ m^2
	Ceiling	tilted roof (30°)	flat	flat	flat
	Dimensions/room	house 82 m^2	$3.35{\times}3.20$ m^2	$2{,}5{\times}4{,}8$ m^2	$3.4{\times}46$ m^2
	Number of twins	1	2	1	1
	Storeys	2	1	1	1
	U-value façade	Building decree	0.05 W/m^2 K	0.20 W/m^{2}K	0.21 W/m^{2}K
	U-value roof	Building decree	0.05 W/m^2 K	0.159 W/m^{2}K	0.164 W/m^{2}K
	U-value floor	Building decree	0.05 W/m^2 K	0.20 W/m^{2}K	0.25 W/m^{2}K
HVAC	Heating	radiator/floor	Fan coil		floor/air
		gas condensing boiler	Air-water heat pump		heat pump/HVAC
	Cooling	yes	yes	yes	yes
	Ventilation	variable volume	variable 187 m^3/h	variable volume	variable 23-300 m^3/h
Control	Smart control system	yes	yes	yes	yes
	Air quality monitoring	yes	yes	yes	yes
Data acquiring and processing	Data equipment and central database	yes	yes	yes	yes
	Real-time process visualisation graphical user interface	yes	yes	yes	yes

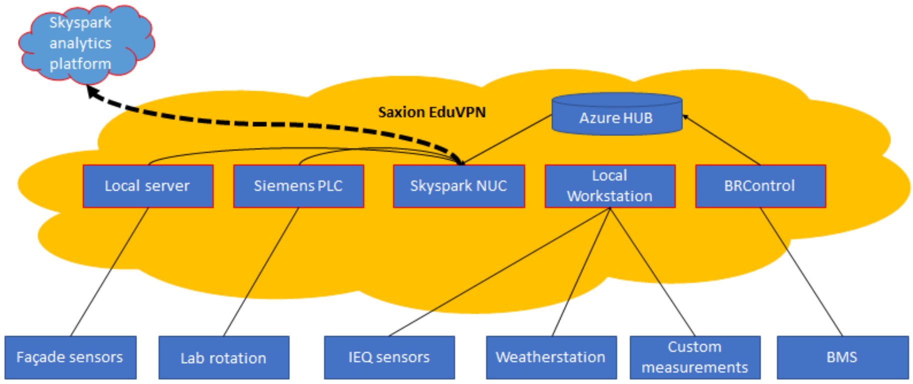

Figure 6. Data acquiring and processing in STL

The BRControls BMS includes multiple forms of automation, such as planning setpoints in schedules, automated season detection, pollution controlled ventilation (CO_2 + TVOC). The sun-tracker regulation is controlled by the Siemens PLC and is directly logged to the SkySpark. The SkySpark gathers and stores data from the different components of STL. IT infrastructure runs locally within the Saxion EduVPN environment. A weather station measures $T_{outdoor}$, RH, wind speed and solar radiation.

4. Smart Tiny Lab in practice

The STL has been designed as a highly reconfigurable lab in terms of façade and heat distribution. This high degree of reconfigurability is required to test the thermal comfort and related energy usage for vastly different concepts of heat distribution. The research packages that the Smart Tiny Lab was designed for are: (1) implementing a sun tracking regulation (2) reconfigurable façade construction with integrated humidity, temperature and heat-flux (3) integrated heated glass pane performance measurements (4) BMS general integration and sensor validity testing (5) total data integration into SkySpark analytics platform and (6) (in progress/future) installation of a battery and comparing DC-grid against AC-grid efficiency, fed directly by the battery, and PV installation on the roof.
Saxion Sustainable Building Technology Research Group has provided companies with the STL the possibility to integrate their products in a rotating and flexible test environment, to increase energy efficiency. Saxion's STL enables experience with innovative materials, products and techniques in buildings. Performances of current test façades on thermal resistance and vapour pressure resistance are investigated. One of the test walls is a “common” construction (vapor open foil + OSB + mineral wool + vapor closed foil + gypsum + wallpaper) where the other is a “sustainable” construction (vapor open foil + OSB + cellulose + OSB).

5. Conclusion

In the newly built Smart TinyLab (STL) building partners and construction-related companies can develop, test, validate and demonstrate their products in practice concerning energy efficiency and indoor climate. STL is also a test facility for new market innovations in the field of energy management and control in conjunction with other systems and solutions. During STL's start-up phase four other European small twin-labs with outdoor setups focused on energy loss of building materials and/or installation and indoor climate were compared. MateLab is more focused on the reaction of inhabitants and is turntable by pick-up. Twin houses Munich are real houses with customizable facades and installations but at a fixed orientation. Test cells Seville are fixed North-South, with only one test façade per test cell. The European outdoor twin test cells, Cells EPFL Freibourg, Demona EPFL Lausanne and Triumf Aalborg have also fixed orientations. The STL is unique in that it has a turning mechanism that allows the entire lab to be rotated 270° towards the preferred orientation or even sun tracking to enable experiments permanent towards or away from direct sunlight. Also having two customizable façade panels per test cell is a benefit. By integrating multiple systems within one test environment, STL has achieved a performance assessment facility to test solutions by integrality and interactivity.

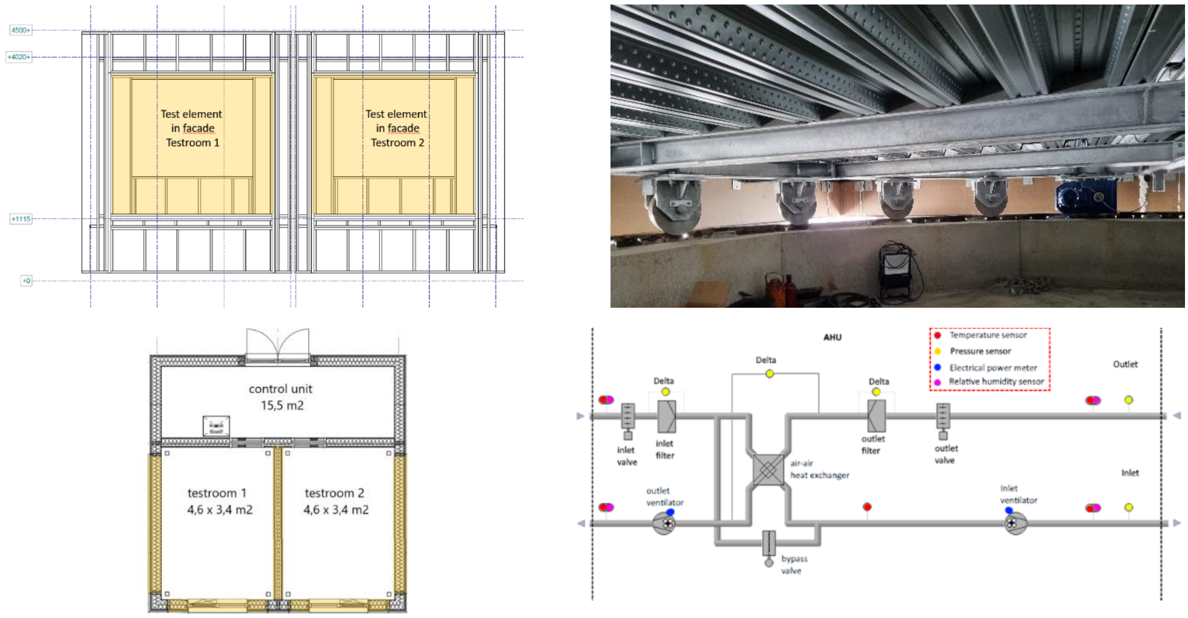

Figure 7. STL Enschede. (top left) customizable façade; (bottom left) ground floor plan; (top right) a turnable with wheels rotates the entire lab (sun tracking); (bottom right) sensors in AHU

6. Acknowledgement

The Smart Tiny Lab project has been realized with the support of OP Oost which falls under the European Regional Development Fund (ERDF). STL was developed by a consortium composed of the following members: Saxion, De Groot Vroomshoop, Pilkington Nederland, BRControls, BINX, Eaton Nederland, Winkels Techniek and Stichting Pioneering. Structural contractor: Dura Vermeer. With the consortium members, the first experiments in the lab started in May 2021, after completion of the lab.

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