Annex to «White Paper SCCER FEEB&D»

Content

1 Most relevant findings

Table 1: Overview of findings from work packages (WPs) 1 to 6, structured according to the paradigm shifts:

Findings	Urban Renewables	Sharing	Flexibility	Algorithms & Data	Capacity	Cooling
WP1	1.1.2 SolAce 1.1.3 Hilo				1.1.1 Efficiency[1]	
WP2		1.2.2 Multi-Energy Systems 1.2.4 Thermal networks		1.2.3 Data driven Control	1.2.1 Most typical retrofit	
WP3	1.3.1 Renewable energy potential	1.3.3 Regional consistent energy packages		1.3.2 Computation of Energy Demand		
WP4	1.4.2 Renewable Decentralized Energy Systems	1.4.3 Best Practice Guidelines			1.4.1 Policy	
WP5						1.5.1 Cooling demand 1.5.2 Urban Morphology 1.5.3 National cooling demand
WP6				1.6.1 Data-based modelling 1.6.2 Machine learning methods 1.6.3 Modelling approaches		

1.1 WP1 Efficiency at Building Scale

1.1.1 Energy Performance Gap

The **Energy Performance Gap** is defined as the difference between the calculated and measured energy use in buildings; it can undermine their contribution to the national carbon reduction plan. Identifying the causes and extent of this gap in Swiss buildings was investigated through the analysis of the GEAK/CECB database containing around 50,000 buildings representative of Swiss dwellings. The study confirms that buildings within low energy

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[1] Retrofitting and the energy performance gap at the national level (WP3) is covered by the analysis conducted in section 1.1.1.

performance classes (classes E, F and G) are more efficient (use less measured energy) than expected by calculations, while energy savings from refurbishments of average building efficiency class (classes B, C and D) may be substantially lower in reality than anticipated.

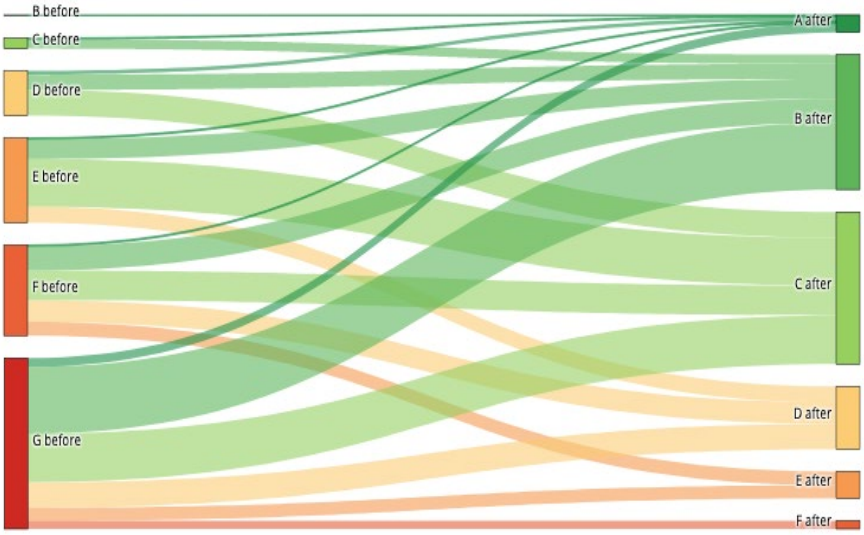

Figure 1: Transition pathways between energy efficiency labels within the Energy Strategy 2050 (S. Cozza et al., UNIGE)

The analysis of a sample of very high performing buildings (class A or Minergie labels) demonstrated that these can meet or exceed performance expectations, indicating that desired performance targets are achievable given sufficient attention to quality and post-construction monitoring [1]. Scenarios for different transition pathways between energy efficiency labels, as well as their potential impact on the Energy Strategy 2050 (ES 2050), have been investigated (Figure 1). A large impact of the Energy Performance Gap on CO_2 emissions was found due to the difference in heating systems between energy labels (only the best labels require low carbon heat supply, such as heat pumps). This highlights the importance of decarbonizing the heat supply first, while implementing energy efficiency measures on the building envelope in a second step [2].

1.1.2 SolAce unit at NEST

The **SolAce unit at NEST** was set-up to meet the highest standards in terms of indoor comfort while achieving an energy positive balance and carbon neutral working/living space. Multi-functional facade technologies issued from SCCER FEEB&D were successfully implemented for that purpose (Figure 2). Coloured nanotechnology-based glazing for PV solar modules and solar thermal collectors [3] led to a positive energy balance over the whole year through the production of solar electricity and heat. Window integrated micro-structured glazing provided a seasonal dynamic management of daylight and solar gains [4]. Laser-treated glazing foster mobile telecommunications while providing a high thermal insulation by the way of a selective glass coating [5]. High Dynamic Range vision sensing technology for blinds and electric lighting control, as well as predictive control of multiple energy subsystems, provided a user-centric approach favouring energy savings of up to 30% compared to a best-practice controller, as well as users' thermal and visual comfort [6]. Space heating demand of 30 kWh/m^2/year, was proven to be very low, while maintaining comfortable thermal conditions throughout 88% of the occupation time in the heating season. The annual energy balance is compatible with the Minergie-A standard, which is remarkable considering that only facades are available for solar energy production. Domestic hot water demand was below 11 kWh/m^2/year with important fluctuations due to the intermittent use of the shower and water taps. Connected to the NEST Energy-Hub network, the solar thermal collectors with an annual production of 40 kWh/m^2/year covered both the space heating and DHW demand, which is 15% lower than the MoPec 2014 prescriptions. Electricity needs of about 20 kWh/m^2/year, a sound figure for an administrative building, were almost entirely covered by the 17 kWh/m^2/year PV solar annual production. Overall, the NEST SolAce unit is energy positive, when considering the space heating, domestic hot water and electric appliances demand, on the way to Minergie-A ECO with further optimisations, a remarkable achievement for a combined office/living space; however, due to its high energy performance, the unit requires an optimal cooling management, involving blinds and windows opening control. Made of prefabricated modular wooden elements and equipped with cardboard-made furniture, the SolAce unit is aiming to foster building materials with low embodied energy and carbon content. Embodied energy is estimated at 40 kWh/m^{2}year, which is below the Minergie-ECO commended limits. By considering the carbon sequestration of the wood products during their lifespan, the unit is very close to carbon neutrality, the 820 kg CO_2 emitted annually by the unit over its lifetime being compensated by the 745 kg CO_2/year stored within wood products during the same period [7].

Figure 2: Outdoor view of NEST SolAce unit involving multi-functional façade technologies issued from the SCCER FEEB&D

1.1.3 HiLo unit at NEST

The **HiLo unit at NEST** is an iconic two-story building located on the topmost platform for which novel structural solutions were used for the building envelope (Figure 3). After several years of research, the combination of traditional building principles and digital technologies resulted in the concept of a reusable formwork for double-curved structures, which consists of a cable net and a membrane stretched over it. The HiLo roof is thus an inspiration for how the building envelope can be rethought and for the new possibilities resulting from the combination of traditional knowledge and digital methods. Thermal insulation by a multi-layered construction, as well as electricity generation on the roof by means of flexible solar cells are among the innovation issued from SCCER FEEB&D, which are featuring HiLo's roof. Genetic algorithms were used to optimize the electrical layout and the design of the PV solar modules [8]. Many household appliances and terminal devices were directly connected to a DC network, in order to avoid inefficient DC/AC and AC/DC conversions. The unit is provided with an Adaptive Solar Façade (ASF), i.e. a dynamic façade of thin-film PV modules with soft, pneumatic actuators for solar tracking and daylight control. The elements provide solar energy generation and shading, as well as control the transparency of the façade [9]. The modules are controlled based on sensors as well as on input by the inhabitants. Adaptive learning algorithms facilitate the continuous improvement of the behaviour and thus the adaptation of the modules to the users and the environment in order to balance between PV solar electricity generation on façade and utilization of solar insolation for space heating and lighting. The HiLo unit will also serve as a preliminary step in investigating the development of district scale coordinated energy management schemes to be tested on several units, which are interconnected through the NEST 'Energy-Hub' infrastructure.

Figure 3: Outdoor view of NEST HiLo unit combining traditional building principles and digital technologies

1.2 WP2 Renewable Energy Systems from Building to District Scale

1.2.1 Most typical retrofitting solutions

Most typical retrofitting solutions for different building types to reach carbon emission reduction targets in the year 2050 have been evaluated [10]. As a target value, 10 kg CO_2/m2 per year which includes both operational and embodied emissions (based on SIA 2040) have been taken as target value. For multi-family houses (MFH) built before 2001 the dominant Renewable Decentralized Energy Systems (RDES) configuration that satisfies the CO_2 emissions target is an air source heat pump (ASHP), with solar renewable technology and storage integration. The choice between PV and solar thermal (ST) differs by site, but in general PV is mostly selected (more than 90%). The situation is similar for storage, where thermal storage is in all typical building intervention solutions selected, and batteries in 75% and 38% of typical solutions for MFH and SFH respectively. For MFH built after 2002 the dominant RDES solutions fluctuate between ASHP and biomass boilers. As for the prevailing building envelope interventions those move from wall insulation and windows replacement to no intervention as the construction year is increasing. In other words, the newer the building the less envelope interventions are suggested. A similar situation is observed for single family houses (SFH) built before 1978 and within 2007 to 2009, where the dominant RDES solutions is also ASHP with solar technology and storage integration, while for there is no clear preference for further measures. The underlying operating and investment costs of the RDES configurations as well as the envelop interventions that satisfy the emission target are also determined per construction class for both MFH and SFH. In general, we can observe higher investment costs for SFH and widely differing investment costs for older buildings.

1.2.2 Multi-energy systems

Multi-energy systems: Our research has demonstrated the advantages of an integrated local energy planning process which: (1) considers potential interactions and synergies between multiple energy carriers/demands (e.g. electricity, heat, cooling), and (2) accounts for spatially-integrated energy solutions at the level of neighbourhoods and districts (e.g. thermal networks). New modelling methods and tools have been developed in the course of FEEB&D to enable the optimized design of local energy systems from an integrated perspective. These methods and tools have been applied to a set of case studies in collaboration with industry and municipal partners (e.g., Stadt Zurich, St. Galler Stadtwerke), in which we have actively supported the planning of local energy systems. These case studies have shown the potential benefits of this approach, specifically in terms of enabling the identification of "win-win" energy supply solutions which simultaneously reduce life-cycle costs and operational CO_2 emissions (in comparison to conventional supply solutions).

1.2.3 Data driven control

Data driven control was successfully implemented in two projects, in the first one [11] to efficiently control the temperature in residential apartments and in the second one to control a multi-energy system in which a heat pump is used to stabilize the electricity grid. In the first project, models of the thermal dynamics of the apartment were developed with different data-driven methods, such as random forests, input convex neural networks and linear regression [11]. Together with weather forecasts, the models can be used for predictive control. In various heating and cooling experiments with the UMAR unit at the NEST demonstrator building at Empa, the predictive controllers saved 20-30% of energy compared to conventional on-off controllers. In the second project [12]-[15], a combination of demand forecasting based on neural networks with online correction methods and robust model predictive control was used to control the interaction of a heat pump with the electricity grid through electric reserves. It was found in experiments with the medium temperature heat pump of NEST that the algorithm is able to help stabilize the electricity grid by ramping the heat pump up and down while keeping the comfort in the building [16].

1.2.4 Thermal networks

Extensive work has been dedicated to further research thermal low-temperature networks. A methodology on the energy efficiency of centralised vs. decentralised circulation pumps was developed and the findings are visualised in a nomogram, helping practitioners to find the best topology in an early planning stage [17]. Methods to safely operate decentralised circulation pumps in thermal networks have been developed [18]. In particular, a valve has been developed to switch the connection point of the expansion vessel in reaction to varying system pressures [19]. A real-size prototype has recently been submitted to ETH Zurich for installation in their network. Pump to pump interactions have been studied within an Innosuisse project that will be finalised this year [20]. In reaction to the challenges experienced in the previous studies, a completely new network topology was developed, the reservoir low-temperature network. This topology allows complete hydraulic decoupling of circulation pumps and therefore meshing of networks [21]-[24]. The relevant findings for practitioners, operators and the scientific community are documented in close collaboration with the programme “Thermische Netze” funded by SFOE [25]. The basic principles of thermal low-temperature networks are described [26] and lead to a publication by EnFK to further help politicians, policy-makers and the public to understand thermal networks and their role in reaching the goals of energy strategy 2050 [27].

In total six manuscripts have been published; two in the peer-reviewed journal Energy [28],[29] and four in peer-reviewed conference proceedings [30],[31],[32],[33]. Additionally, a valve has been developed that reduces the absolute pressure in district heating and cooling networks. The valve has been tested, patented (patent no. 01308/17) and a real-size prototype has recently been submitted to ETH Zurich for installation in their network. Together with Belimo, a control strategy for energy transfer stations has been developed and a real-type prototype is currently being tested in a district heating network in Naters, Switzerland.

In the six manuscripts, three topologies for district heating and cooling networks have been studied. The topologies differ in their circulation pump locations and pipe layouts. The bidirectional topology avoids mixing of warm and cold fluid and thus makes optimal use of the temperature levels for heating and cooling. This topology consequently operates heat pumps (and chillers) most efficiently. The reservoir network, a new network concept, almost achieves the same efficiency (within 1%) as the bidirectional network if operated correctly. The traditional network configuration with one central circulation pump requires 1% to 5% more electricity than the bidirectional design.

In summary, the different network designs, if operated correctly, can achieve similar energy efficiencies within approximately 5%. Robustness, flexibility to expansion, simple control and costs (investment and operation) are thus the main drivers for decision-making.

1.3 WP3 Energy Performance at Regional and National Scale

WP3 had the objective of gaining a better understanding of the energy demand as well as of the energy resources at the national scale. To this end, we used a variety of approaches (machine learning, statistical methods, deterministic modelling and geographical information systems analysis). We give the details of three of the main findings and their implications for the Swiss Energy Strategy below.

1.3.1 Renewable energy potential

Renewable energy potential. A detailed evaluation of three different renewable energy resources (solar, shallow geothermal and wind) was conducted for Switzerland. A combination of Machine-learning algorithms and GIS techniques was used to process the input data and to select the most important parameters for the evaluation of the considered resources. Each of these resources was computed at high resolution (pixel of 200m*200m). The solar rooftop potential was quantified according to rooftops category, slope and aspect. A realistic strategy was applied to place photovoltaic panels over the 9.6 million rooftops, bringing to an estimated potential of 24+/-9 TWh p.a. [34]. This represented more than 40% of the electricity demand recorded in 2018. For the quantification of the geothermal energy, the physical potential for geothermal heat pumps was assessed using the thermal conductivity, thermal diffusivity and ground temperature gradient. The current study has demonstrated a capacity of 11.8TWh p.a., which is equivalent to 17.8% of the thermal heating demand. A potential of 4 TWh p.a. has been derived for the meeting the cooling demand. Finally, a theoretical wind potential was estimated within the rural areas of Switzerland. More specifically, monthly mean wind speed data for 108 locations, was used to train a machine learning algorithm (Support Vector Machine) together with monthly weather features (sunshine duration, precipitation, cloud cover, and air temperature) and terrain features (latitude, longitude, altitude, and slope, aspect, and curvature of the terrain). The estimated wind energy potential was of 1.2TWh (~2% of the electricity demand of 2018). These studies are now being extended in the framework of the National Research Project 75 Big Data, HyEnergy for their quantification at high spatial and temporal resolution.

1.3.2 Computation of the energy demand.

Computation of the energy demand. For the heat demand, a statistical bottom-up model for current heat demand per-building was developed and calibrated using measured data. The technical potential for energy savings from retrofitting to Minergie standard was calculated on the basis of a building retrofit potential and cost model for the Swiss residential building stock. This has been used to develop a calculation method for identifying attractive areas for district heating and linking these with potential energy sources [35],[36]. Today’s potential heat demand potential that could be supplied by district heating and thermal grids (HTDH or LTDH) amounts to 58 TWh/year or 66% of total demand, thereby covering 40% of all buildings [37] (for comparison: the total final energy demand of all multi-family-houses amounts to 46% of the residential sector's total final energy demand [1]). Due to the improved thermal performance of buildings (deep energy retrofit, new buildings) the role of district heating and thermal grids is expected to somewhat decrease in future but it nevertheless remains significant, amounting to 23-33 TWh/year or 53% to 60% of total demand [37].

Levelized cost of small heating grids (e.g. with ground source heat pumps) are typically comparable to costs of oil and gas boilers as well as decentralized small air source heat pumps. Large-scale district heating using low-priced industrial excess heat is comparable in cost for multifamily houses (in denser urban areas) while its cost is clearly higher for single-family houses. Large-scale district heating using other heat sources (e.g. large heat pumps) is clearly more expensive [38].

According to scenario projections [39] a pronounced transition from old to new buildings can be expected in particular for multifamily houses. Despite this natural replacement the annual energy demand and greenhouse gas emissions can be expected to decrease only by a quarter until 2060, with still high investment cost for refurbishment (heating replacement and non-energy measures) of the aging building stock. This will not be sufficient to approach net zero greenhouse gas emission target for 2050. A large-scale retrofit of the entire existing building stock is therefore indispensable. This study identifies different retrofit pathways according to a combination of economic and environmental objectives. As one key finding, both pathways aim for an increase of the retrofit activity as early and as fast as possible in order to benefit from the long-term gains. Based on these conclusions, it is crucial to discourage refurbishment or light retrofit options based on the lowest investment cost and instead encourage early and deep retrofit [39].

Cooling demand for the present day and for several climate scenarios has been calculated for offices, hotels, trade, and health buildings [43]. Cooling demand is expected to grow between 370% and 580% in these sectors from 890 GWh ± 200 GWh/year in 2015, driven mainly by increased adoption of air conditioning. Electricity Load Curves were updated in the tool originally developed by SIG for estimating annual average electricity load curves for dwellings and for the main service (e.g. private and public offices, schools etc.) and industry sectors (e.g. chemical, food and beverage). This work has been finalized and is available via an online service (www.electrowhat.ch). The clustering method developed is used to identify load profiles and linked to household characteristics. A bottom-up model that generates typical Swiss household hourly electricity demand profiles per appliance based on time of use data and appliance ownership was validated by monitored data. This was done to estimate the impact of energy efficiency measures and policies such as minimum energy performance standards on the peak load. For heat pumps and other electrification strategies, an advanced study of the CO_2 intensity of marginal electricity demand will offer additional insight. The modelling results showed that the appliance electricity consumption can be reduced by 21% and 38% for noon and evening peak periods respectively when the appliances are replaced by the highest energy efficiency label available on the market. The evening appliance peak demand could reduce in 2035 by 24% thanks to the improvement of the energy performance of the stock. Changing light bulbs to LED has the highest potential to decrease the evening peak demand, which corresponds to a 18.8% decrease in total appliance electricity demand, 14.2% decrease in overall residential electricity demand and 5.0% decrease in the total national electricity demand [44].

Self-consumption (SCo), i.e. the share of auto-consumed self-generated PV electricity in single-family houses with a heat pump system (for space heating and domestic hot water) with thermal storage and under the assumption of a capacity tariff (electricity) is in the range of 30-40% depending on the building's thermal performance. Similar self-consumption values (30-40%) were achieved in single-family houses with PV panel and battery only (without thermal storage), again under the assumption of a capacity tariff. Self-consumption shares are on the high side for buildings with low thermal performance and vice versa. Self-sufficiency (SSu), i.e. the share of total electricity demand covered by auto-produced PV electricity, was also found to depend on energy storage, partly with similar values as for SCo. Without energy storage the values ranged from nearly 20% (for low thermal performance) to somewhat above 30% (for very high thermal performance), whereas *with* thermal storage and *with* inclusion of domestic hot water, values of nearly 25% to somewhat above 40% were achieved. Clearly higher values for SSu were achieved with battery systems in buildings with high to very high thermal performance (up to 30-60%). Increased Self-consumption (SCo) is important to improve economic viability but other applications offered by batteries serve this purpose, too. Demand load-shifting, demand peak shaving and avoidance of PV curtailment allow batteries to nearly reach break-even and to increase their net present value by up to 66% (compared to batteries with PV self-consumption only) [40]. It has been confirmed by other studies (e.g. [41]) who showed that the combination of demand peak shaving and PV self-consumption added most value.

For a single-family house (equipped with heat pump, PV, battery and thermal storage) with a mediocre thermal performance (100 kWh/m^2/a) the peak flow of is approximately 2 ½ higher than for buildings with high to very high thermal performance (15-45 kWh/m^2/a). In buildings with mediocre thermal performance, the heat pump operation strongly impacts the peak load (e.g. doubling of the original load) while it has only a rather small impact on the peak load for buildings with high thermal performance for (due lower power levels and non-simultaneity) [42].

1.3.3 Regionally consistent energy packages

Regionally consistent energy packages [45]. The work conducted here extended the modelling capabilities of the energy hub modelling framework to allow the evaluation of energy solutions at the regional scale, while also maintaining reasonable computational requirements. The identification of the optimal energy system for a complete region with high accuracy and low computational cost remains a challenge. Clustering methods employed together with optimisation methods have shown to be a promising approach to facilitate large scale modelling and optimisation of urban energy systems. These approaches enable tackling large-scale problems while accounting for the losses in accuracy by developing intelligent clustering schema, reducing the possibilities to end up in sub-optimal solutions. In addition to this work, studies have also been conducted to demonstrate the impact of regional planning scenarios (including large-scale retrofit) as well as climate change on the energy demand of the building sector. The impact of these variations on the energy systems were finally evaluated.

1.4 WP4 Diffusion of FEEB&D Technologies

1.4.1 Policy

Policies aiming at accelerating energy efficient and renewable building technologies need to be tailored to the technologies' lifecycle (temporal), their technological setting (interaction), and their regulatory context. Responsive policy adjustments over time can better account for rapidly decreasing technology costs and might produce policies that follow their targets more closely, at a lower cost, and with less uncertainty [46],[47]. Such temporal evolution of policy instruments however, only works if cross-technology effects are considered. Feed-in remuneration for solar PV might, for example, disincentivize battery diffusion. A careful orchestration of different policy instruments is therefore pivotal to achieve best system outputs (e.g. emission reductions and policy costs)

[48][49]. The optimal mix and path of such instruments (e.g. subsidies, regulation, information campaigns, labels) also depends on the maturity, modularity, and cross-technology interaction as our analysis of heat-pumps, comfort ventilation and low-e glazing shows [50],[51].

1.4.2 Renewable decentralized energy systems

Renewable decentralized energy systems (RDES) – a collection of production, conversion and storage devices with at least one renewable energy source – exist in a vast range of technical configurations, settings, and applications [52]. In dense urban areas and grid-connected settings, such systems are already cost competitive especially for new developments [53]. However, for existing districts increased retrofitting will be required to achieve the ES2050 energy efficiency targets in combination with RDES [54]. The development of RDES are distinctively different from standard construction projects as they show greater technological (e.g. interconnections, local renewables, usage synergies, smart applications) and strategic (e.g. sustainability focus, prosumers) complexity. This requires construction industry stakeholders to adapt and change their established roles in the process [55],[56].

1.4.3 Best-practice guidelines for innovating energy-efficient building technologies

Best-practice guidelines for innovating energy-efficient building technologies - To support Swiss providers of energy-efficient building technologies in their efforts to successfully develop and commercialize their products in the building sector, we identify important innovation patterns.

Business ecosystems – a connection between several companies to jointly create an offering – was identified as a promising approach for new energy-efficient building technologies. Innovation in the built environment is mainly driven by large companies (incumbents and newcomers) for modular technologies, and to a smaller extent by small incumbents for complex technologies. While simple modular technologies are relatively easy to develop and commercialize, complex ones, which might be more efficient at reducing energy consumption, still face difficulties. While large incumbents have few incentives to develop complex technologies, small newcomers, familiar with modern innovation practices, have few opportunities to succeed in the building industry. Nevertheless, their specialized knowledge would be useful in specific situation. Finally, as in many other areas, digitalization is rapidly transforming the industry [57]. As a consequence, we recommend the creation of a business ecosystem based on the exchange of data on the local technology setup, demand profiles and customer characteristics.

The ecosystem should provide a clear economic return for the connected technology providers and feature a viable and protected business model for the ecosystem lead. Analogies can be found in providers of systems solutions such as for Android-based mobile devices or Amazon-type online sales platform.

Current business models (BM) within the decentralized electricity domain (such as PV installations or self-consumption optimization) do not differentiate sufficiently between different end-user markets. For example for self-consumption optimization the value proposition for consumer and business customers does not differ much and focusing on economic and functional aspects [58]. However, offerings persisting for a longer time have shown to including an ethical/ component within their value proposition. This was identified as a hurdle to scale existing business models to other markets. At the same time, there are examples of more customer-oriented business models observable within the international context. Those business models tend to be successful in terms of accelerating the energy transition. In order to adapt those business models to the Swiss market, comparable elements need to be identified. A reliable taxonomy of business model elements and a database of observed business models greatly speed this process up [59].

1.5 WP5 Urban Planning for Smart & Resilient Cities/Communities- Cooling

1.5.1 Cooling demand in Switzerland will increase substantially

Until 2050 cooling demand in Switzerland will increase substantially, primarily but not only in urban areas (see 1.3.2) [43]. It is thus important to focus on future cooling solutions for individual buildings but also on an urban scale. Multi-scale analysis confirmed the importance of studying various urban planning scenarios to assess their impact on urban comfort and resilience to climate change and extreme weather events such as heat waves.

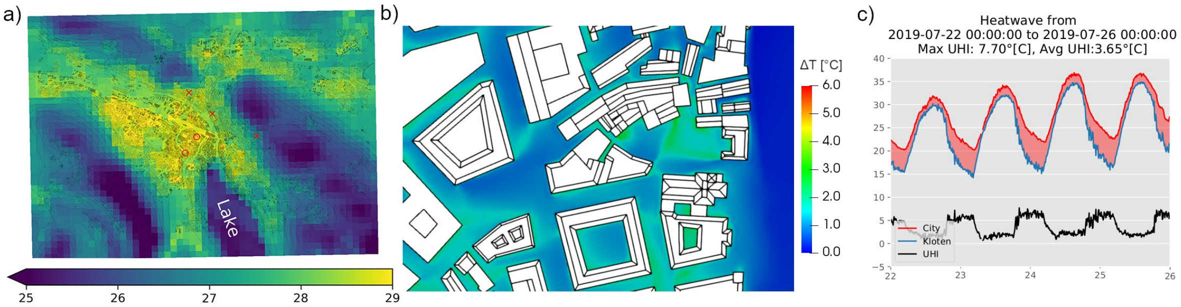

Figure 4: Air temperature in Zürich using mesoscale weather prediction model with urban parameterization; b) local scale detailed numerical simulation around Münsterhof, Zürich; c) urban heat island intensity in Zürich during heat wave, 22-26 July 2019

1.5.2 Urban morphologies have a great impact on building's cooling demand

In an urban context, urban morphologies have a great impact on building's cooling demand but also urban materials, green areas, shading from trees, etc. Evaporative cooling solutions by selective use of porous urban materials and optimization of artificial wetting have been studied and were proven to lower the peak air temperature and heat stress during heat waves [60],[61],[62]. On a building level, different passive and free cooling approaches were assessed and evaluated for potential building retrofits. Passive measures such as window shading and night ventilation remain an important measure for indoor climate control [63]. An interesting free cooling approach was found in applying PVT collectors as heat rejection devices using night sky radiation to unload thermal mass of the building for protection against overheating during the day [64].

1.5.3 National level cooling demand studies were performed

National level cooling demand studies were performed, both, using physics-based and data-driven methods. While results for residential buildings are not yet compiled, analysis for the service sector identified a cooling demand of 890 ± 200 GWh/year in 2015 with a strong increase of cooling demand until 2050 in all three climate change scenarios: 370% in representative concentration pathway (RCP) 2.6, 500% in RCP 4.5, and 580% in RCP 8.5 [43]. Growth in space cooling saturation rate (180-200%) is the major driver of demand growth, more than increases in total service area (35%) and cooling intensity (30-70%). The results suggest that current space cooling demand in service sector is approximately 7% of space heating demand. However, by 2050 it will be equivalent to more than half of space heating demand in all three RCP scenarios.

Final energy for cooling amounted to only around 10% of the total useful energy demand (heating and cooling) 10% and it may increase to 50% future. The simultaneous presence of cooling and heating per pixel (200m x 200m) is rather un-common in Switzerland, with cooling-to-heating ratios above 20% currently representing a relative frequency of less than 1% (Li et al., UNIGE, in preparation). Under a strong global warming scenario this percentage is expected to clearly rise.

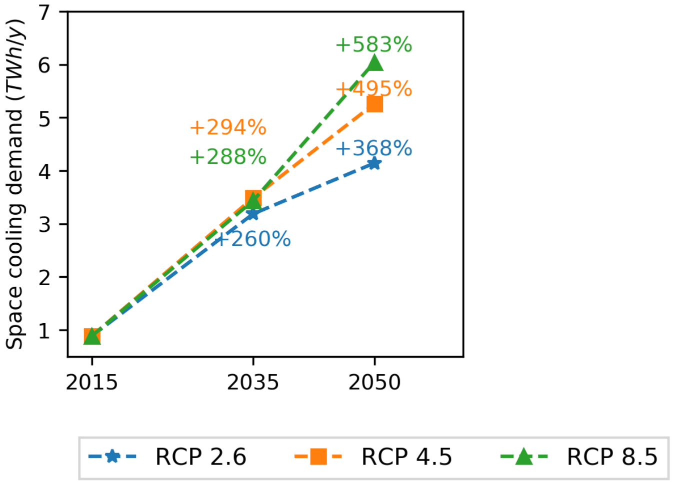

Figure 5: Estimation of cooling demand of the service sector under climate change scenarios by 2050.

1.6 WP6 Leveraging Ubiquitous Energy Data

1.6.1 Data-based modelling methods

Data-based modelling methods have been advanced with the objective of making advanced energy management and control systems deployable at the smaller building scale [65],[66]. Low cost sensors (for temperature and glare for example) have been incorporated into apartment control for thermal and visual comfort. A combination of historical data and sensor measurements has been successfully applied in the semi-automatic development of predictive models for minimizing energy while maintaining user comfort. Implementation tests are ongoing in several Empa NEST units [67].

1.6.2 Machine learning methods

Machine learning methods have been explored to identify typical patterns as well as anomalous patterns in building electricity consumption time series. The effectiveness of both supervised and unsupervised methods in triggering possible anomalies on a weekly basis has been investigated. Different building types, ranging from supermarkets to the IT servers and commercial shops of the Swisscom-owned buildings, have been considered. Preliminary results show great potential in clustering anomalies using offline data. For normal operation, typical consumption patterns exhibited in residential buildings can be identified by making use of smart meter data as well as socio-demographics collected via trials and surveys. The analysis highlights the heterogeneity of the households in their daily activities as well as their capacity and willingness to be involved in demand side management schemes (e.g. retired versus families with children).

1.6.3 Two modelling approaches: a) Lumped resistance-capacitance (RC) thermal models and b) Machine learning (ML) prediction models

Two modelling approaches (a) Lumped resistance-capacitance (RC) thermal models and (b) Machine learning (ML) prediction models have been successfully applied to derive cost-optimal retrofit solutions. Both rely on in-situ measurements obtained using wireless sensors [68]. The RC modelling shows that it is possible to automate the retrofit process provided there is sufficient knowledge on the boundary conditions of the thermal properties of the retrofit measures [69]. The ML models allow the analysis of the significance of the inputs [70]. A single-family house case study has been used to validate this approach, and to quantify the contribution of the retrofit options with respect to energy savings. The models developed for retrofit evaluation are compatible with the predictive control methods that can be used to optimize the energy use in the retrofitted building, thereby reducing the effort needed for control system tuning and commissioning.

1.7 Impact

The building sector is responsible for 45 % of the overall energy consumption (230 TWh, 2018, BFE) and 25% of the CO_2 emissions (37'000 kto, 2018, BAFU). The research within the different work-packages finally interact and lead to implementation of the findings with an impact on energy and CO_2 emissions. It will be necessary to process such implementation as foreseen, which is a complex action including all stakeholders of the energy sector and also including all findings of the other SCCER. As far as it concerns the SCCER FEEB&D we broke down to all single tasks and subtasks and calculated the potential impact on CO_2 reduction and overall energy consumption reduction for the building sector. The energy consumption can be reduced by about 50 TWh. Decarbonisation of the building energy sector will reduce the CO_2 emissions by about 7'000 kto. This means the impact is very significant but not large enough. The outcome of all other SCCER are necessary and it also means that all of the following recommendations are of the essence and need to be considered.

2 Key recommendations to politicians and the public administration

2.1 WP1 Efficiency at Building Scale

1. The renovation rate of the Swiss building stock is too low and must be accelerated. The annual renovation rate of the building stock in Switzerland is less than 1.5% [71]. At this rate, the renovation of residential and tertiary buildings will take more than 50 years, which is far too long in view of the timetable of the ES 2050 and the commitments made by Switzerland in the framework of the Paris Agreements. The renovation rate must be accelerated, as the current incentives are insufficient in this respect. While not being the optimal approach, the lower capital requirements may make many owners prioritize low-carbon heat supply (e.g. by substituting fossil-based central heating by heat pumps) and to implement energy efficiency measures in buildings in a second step. This raises numerous questions about advantages and disadvantages (e.g., impacted of over-dimensioned heat pump system). Furthermore, new approaches for technical energy regulations must be considered [72], if one wants to achieve the strategic ES2050 and CO_2 mitigation objectives of the Paris Agreement, while enabling innovation and ensuring implementation of energy efficient and renewable energy technologies.
2. Building envelopes offer a considerable potential for renewable energies and must be fully used. The production of renewable energy using passive and active solar technologies is a promising way of achieving the objectives of the ES2050. The available surfaces at the level of the building envelope, whether roofs, facades and/or glass openings, are ample and offer many integration opportunities of solar technologies in buildings. Innovative glazing technologies can foster solar gain and daylighting within buildings [73]. In terms of aesthetic requirements, the range of coloured solar collectors on offer today already meets demanding criteria for integration into buildings [74]. To date, these new technologies still represent a niche market, due to the lack of awareness on the side of project owners and contractors, the lack of social and political incentives, as well as the costs, which often remain prohibitive.
3. Fostering energy efficiency and renewable energies in buildings through a targeted regulation. Many building technologies are? needed to adapt the current energy system to the requirements of the ES 2050 are already available. Mere volunteering is not enough, especially in the building sector, to ensure their widespread dissemination. Regulatory interventions, in addition to financial incentives, are absolutely needed. Energy-efficient measures, as well as renewables integration in the building envelope, require additional regulations and financial support [72]. Moreover, incentives such as the Confederation Building Program must be increased in order to accelerate the building renovation rate and foster the overall operational processes.

2.2 WP2 Renewable Energy Systems from Building to District

1. Targeted incentives to support the optimal retrofitting interventions for the existing building stock of Switzerland
2. Incentives for integrated energy planning of communities.
3. Data-driven control has the potential to significantly reduce heating energy in the residential sector with easy and cost-effective controller retrofits (e.g. through exchanging conventional radiator- and wall thermostats with predictive controllers). However, there is no economic incentive for property

owners to retrofit (because they pass on the heating costs to tenants), and only a limited incentive for tenants themselves to retrofit, partly because heating costs are generally not individually billed per household in Switzerland. By making individual billing mandatory, the incentive for tenants to install predictive (and thus more efficient) controllers could be significantly increased.

4. Low-temperature thermal networks providing both heating and cooling are recommended because they promise to significantly boost the integration of new renewables and waste heat into the Swiss energy system, thus lowering its CO_2 output considerably.
5. To successfully optimise operations even in residential buildings (see module 8, MuKEn:2014), monitoring processes need to be put in place and have been shown to lead to energy savings of up to 20 % using cheap and abundantly available sensor technology and selective user-intervention.

2.3 WP3 Energy Performance at Regional and National Scale

1. There is a necessity to conduct more studies at regional level and to scale these up to national level because local circumstances can differ considerably, e.g. with regard to economic structure (e.g. urban, rural, industrial; pre-existing infrastructure) and natural boundary conditions (e.g. urban microclimate).
2. To this end, the combination of this work package with other projects such as the NRP 75 – Big Data project can help to develop new synergies to build a more thorough and comprehensive database at the Swiss national scale. The combination of Machine Learning and GIS techniques will allow to reach a higher level of spatial and temporal resolution and this methodology offers interesting perspective to extend future study on the evolution of renewable at the national level.
3. It is possible to reach 75% of the estimated rooftop PV potential by installing the PV technology mostly on flat rooftops, which represent less than 35% of the total buildings in Switzerland (see Figure 6).

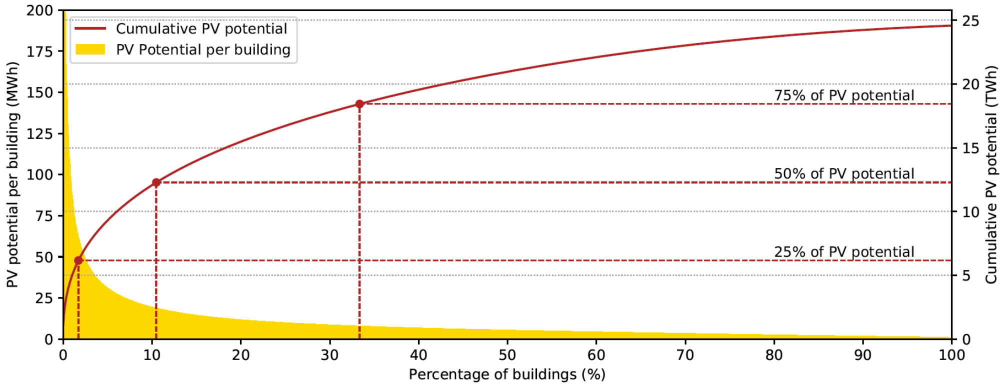

Figure 6: Cumulative PV potential and PV potential per building as a function of the percentage of buildings in Switzerland [34]

4. The newly developed methodologies are flexible in terms of scale: while they were designed for assessments for Switzerland as a whole, they make use of specific local variables and therefore lend themselves, in principle, also for analyses for cantons, cities or even large neighbourhoods. This entails interesting development potential beyond the national scope.

5. The geospatial analysis mapping energy demand and the potential for district heating and other decarbonised heat technologies as well as low carbon heat sources should be used by local energy planners to evaluate the energy transition options available to them, for example integration with industrial waste heat supplies.

6. The future increase in demand for cooling should be taken into account by planners in the design of energy systems, notably through considering combined heating and cooling district thermal networks using low exergy technology.

7. Furthermore, there should be long-term support for the development of energy data and planning decision support tools based on the output of this research, that facilitate open access data and knowledge sharing.

8. Policies must urgently address the very low rate of thermal retrofit of buildings in the residential sector. The high costs in Switzerland, driven primarily by high labour costs, have been highlighted as a barrier; therefore radical cost reduction policies are needed. This should include increasing competition through openness to the European market, as well as measurement and enforcement measures to ensure that works are conducted in accordance to standards. In addition, optimal combinations of demand reduction and decarbonisation of heat supply should be explored.

9. Both energy efficiency and demand response are seen as vital to support the integration of renewable energy technologies. Reductions can be achieved both in morning and evening peak periods by buying more energy efficient appliances rather than shifting the appliances to off-peak. Policy-makers thus should envisage a combination of interventions aiming at replacing the appliances of with higher efficiency models and light bulbs with LED technology for those households less willing to participate in demand response schemes, as well as promoting appliances that households find more acceptable and feel less limited to shift such as washing machines, tumble dryers and dishwashers.

2.4 WP4 Diffusion of FEEB&D Technologies

1. Policy-makers designing and implementing deployment policies for energy efficient and renewable building technologies should pay specific attention to the temporal adjustability of economic incentives. Cost decreases of renewable energy technologies - especially for solar PV and more recently, li-ion batteries – outpaced all expectations. Further, cross-technology and cross-sector effects (e.g. with the mobility sector through the integration of electric vehicles) require more holistic policy solutions in the building sector. The multi-facetted approach the MuKEn:2014 takes – despite being debated – is a step in this direction on the building energy code level [75][76],. It not only aspires to harmonize the regulation across cantons but also links multiple policy instruments, as it builds on labels (i.e. Minergie), relates to certification (i.e. GEAK), and refers to economic incentive programs (i.e. HFM).

2. Renewable decentralized energy systems (RDES) have a great potential to facilitate the integration of renewables in the building sector. Especially for dense new areal developments, such systems should become the standard for cost-effective and low-emission energy systems. However, achieving the ES2050 in existing districts with RDES is considerably harder, as multiple ownerships, the need for increased retrofitting, and technological constraints complicate the matter. Nevertheless, to fully decarbonize the heat supply in dense urban districts where air and ground-sourced heat pumps might be restricted, RDES could be the only remaining option. Setting strategic goals (e.g. CO_2 reduction path)

while keeping the regulation flexible (e.g., energy codes on the areal instead of the building level) might provide the required framework condition of RDES to thrive. Especially, if such approaches are aligned with programs in adjacent political realms such as zoning or tenant laws.

3. Our results identify two major trends that affect innovation in the building industry. First, the entrance of new market players, both large ones and entrepreneurial ventures, with substantively different skill-sets and resource endowments. Second, the increasing diversity of building technologies, in particular those that draw on basic digital technologies (e.g., IoT, Big Data, Artificial Intelligence) [77],[78]. To benefit from these two trends, we recommend policies targeted at changing the underlying structure of the building industry that reduce price competition, consolidate the industry, and nurture risk-taking and entrepreneurial behaviour from large incumbents. Companies in the building industry should also quickly develop digital capacities to be able to compete in the market in the end. Finally, the recent wave of innovation in building technologies has substantive ramifications for companies' workforce and the national labour market, as the increasing need for digital talents lowers the overall employment opportunities in the industry and the demanded talents. While policy-makers need to adjust labour market and education policies to these changes, businesses will have to rethink how they hire and motivate employees in the future.

4. Targeting broader market segments, such as end users, to participate in the energy transition is still underdeveloped. To this end, we recommend to research ways to standardize the offerings more in order allow for cheaper channels than a sales force and hence lower costs. Further, current offerings tend to focus too exclusively on typical engineering arguments such as functions and costs when targeting the consumer sector. We generally recommend including emotional and ethical values for the consumer market. Additionally, for product owners who wish to include a recurring payment system for their offerings, we recommend to present a strong social, ethical and emotional component in their value proposition.

2.5 WP5 Urban Planning for Smart & Resilient Cities/Communities- Cooling

1. Current and future planning should take into account both, the increasing frequency and intensity of heat waves due to climate change and the local urban microclimate and heat islands in the analyses of building energy use and thermal indoor and outdoor comfort. Strategies and adaptation measures including a closer look at the regional setting (urban heat island mitigation) have to be evaluated when developing new urban planning scenarios. It is necessary to use tools that can take into account the multiple coupled physical processes taking place at different levels / scales. This is crucial as mitigation measures can have a multitude of effects and – for successful implementation – often a combination of mitigation measures is necessary.

2. A key policy priority should be to plan for the considerable, potential increase of final energy consumption for space cooling in the future. For instance, policy makers, researchers and other stakeholders should evaluate the effectiveness of alternative cooling measures, such as night ventilation and district cooling networks, and develop adaption strategies to tackle the expanding demand for space cooling. Moreover, it would be advisable for policy makers to regulate the use of air conditioners in advance and promote environmentally friendly cooling solutions (e.g. solar, geothermal cooling systems) along with defining limits for allowed waste heat rejection to the ambient.

2.6 WP6 Leveraging Ubiquitous Energy Data

1. There is a strong connection between the level of digitalization of the building and energy sectors and the potential for energy and CO_2 reduction as well as improved occupant comfort. Advanced control systems, capable of cooperating with neighbouring systems in an energy network are able to exploit flexibility and shared energy resources to gain these efficiencies. Doing so requires coordination on both short and longer time scales than can only be achieved with automated energy management systems. Standardizing interoperability and information interfaces will be necessary for wide-scale implementation involving multiple system manufacturers. The application of Machine Learning based methods on recorded data can further enhance automatization, specifically by quickly spotting anomalies in energy consumption patterns. This can bring a significant increase in the long-term efficiency of a building energy system. Data systems and digitalisation has a potential positive impact on the construction, repair and retrofit aspects of buildings. The tracking of data related to construction materials (in building information modelling (BIM) frameworks) facilitates the enhanced reuse of materials and targeted retrofitting in the building sector.
2. The development and deployment of data analysis methods at a large scale has the potential to identify and exploit energy saving and CO_2 reduction opportunities in a variety of ways. Low cost and easily deployed sensing can be used enhance models for energy management as well as the potentials for retrofit. A data-driven modelling framework allows analysis of the sensitivity of the model inputs for achieving an accurate cost-optimal retrofit solution. The measured data can also be used to inform building owners about the performance levels of their buildings and can be used to identify potential for load shifting/demand response control. Data analysis at a regional scale can identify additional potential generation capabilities, particularly with regard to solar potentials.
3. Evidence from data collected via trials and surveys, coupled with modelled data, suggests that motivating more flexible and energy efficient behaviour (e.g. shifting to off-peak, buying more energy efficient appliances) is possible amongst certain end-users. Stronger emphasis on home automation systems for load shifting should be made in order to involve households that are not present in the afternoon and can provide electrical load flexibility, in demand side management (DSM) schemes to more successfully match electrical demand with photovoltaic (PV) supply.

2.7 Knowledge and Technology Transfer

The implementation of holistic energy and CO_2 efficient solutions at building and district scale involve typically several industry sectors, as well as the public sector. Standardisations and simplified planning and execution processes are needed. This will allow for better training of professionals to gain a global overview and strengthen cooperation across disciplines. The effectiveness of the solutions can be increased through better-coordinated planning, execution and operation phases, in addition to lower planning costs and risks.

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