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ULISSE

Under Lake Infrastructure for thermal capture and Storage of Solar Energy

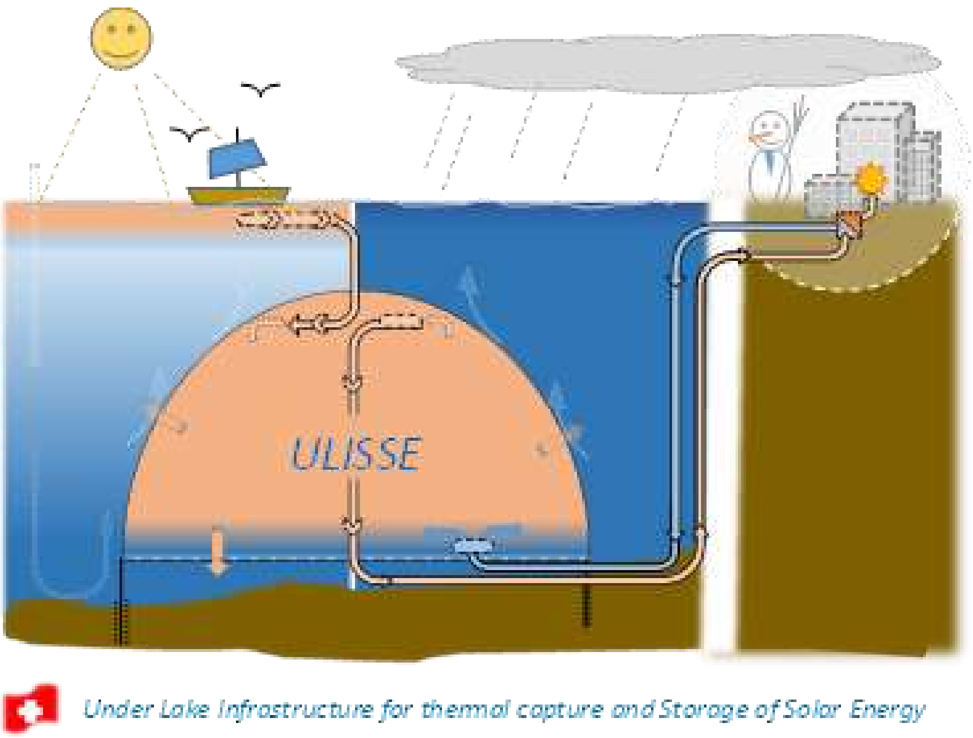

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Table of Contents

Summary **5**

Résumé **6**

Zusammenfassung **7**

Riassunto **8**

Foreword **10**

Acknowledgements **10**

1 Introduction **11**

1.1 Context and state of the art of research 11

1.2 Unconventionality and originality of the project 16

2 Objectives **17**

3 Results and discussion **18**

Part A: Technical and energy considerations **19**

3.1 The ULISSE Reservoir concept 19

3.1.1 Overall design 19

3.1.2 Anchoring 19

3.1.3 ULISSE lake water collector and storage device 20

3.1.4 Reservoir operation (Loading & Discharging cycles) 21

3.1.5 Envelope 22

3.1.6 Hyperbolic transverse shape of the ULISSE Reservoir 23

3.1.7 Properties of the constituent materials of the ULISSE Reservoir envelope 24

3.1.8 Analysis of the heat transfer by the envelope of the ULISSE Reservoir 25

3.2 Experimental Mock-up 27

3.3 Time Scale Factor (TSF) of Real full-size Ulisse Reservoir vs Mock-up 30

3.3.1 Dimensional analysis 30

3.3.2 Energy balance of the real ULISSE Reservoir and the Mock-up 31

3.3.3 Theoretical calculations for the real ULISSE Reservoir 33

3.3.4 Theoretical calculations for the Mock-up 34

3.3.5 Theoretical and experimental energy balance of the Reservoir and the Mock-up 35

3.3.6 Numerical simulation of the ULISSE type Reservoir and the Mock-up 36

3.4 Analysis of the GeniLac Thermal Lacustrine Network 41

3.4.1 Description of the GeniLac system 41

3.4.2 Lake Water Temperature Impacts 41

3.4.3 Integration of ULISSE into the TLN GeniLac Network 43

3.4.4 Association of CORSAIRE free heating with ULISSE at GeniLac 44

3.4.5 Variant of integration of CORSAIRE free heating in the building 44

3.4.6 Conclusions for the GeniLac Thermal Lacustrine Network 45

3.4.7 Connection of the TLN GeniLac to the ULISSE Reservoirs 47

3.5 National potential for setting up and saving electricity by ULISSE and CORSAIRE 50

3.5.1 National potential of ULISSE and CORSAIRE “internally” (via the TLN) 50

3.5.2 National CORSAIRE potential via the DWN excluding TLN or lake regions 52

3.5.3 National potential for electricity savings and investment by ULISSE and CORSAIRE 52

Part B: Environment and lake users' considerations ... 54
3.6 Environmental and cohabitation aspects ... 54
3.6.1 Location ... 54
3.6.2 Type and quantity of materials used ... 54
3.6.3 Interaction with the lake ... 55
3.6.4 Co-existence with lake users (navigation, fishing) ... 56
Part C: Economic considerations ... 58
3.7 Estimation of financial investment cost of the ULISSE Reservoirs ... 58
3.7.1 Comparison with large hydrothermal storage systems ... 58
3.7.2 Land area for the solar collectors and the thermal storage basin ... 59
3.7.3 Summary comparison of ULISSE with alternative solutions ... 60
3.8 Overall discussion ... 61
4 Cooperation and coordination with SWEET consortia and SOUR projects ... 62
5 Outlook and next steps ... 62
6 Outputs and outreach ... 67
7 References ... 68
Appendices ... 71

Summary

Faced with climate change, the *Swiss Energy Strategy* 2050 (SES-2050) is aiming for *"double neutrality"* *nuclear & carbon* (2035-2050) and forecasts a structural deficit in the winter semester of 9 TWh of electric energy (equivalent to the national hydroelectric storage capacity). This is the result of the planned withdrawal of nuclear power in 2035 and the increase in demand for electricity, for electric mobility, heat pumps for air conditioning, room heating and domestic hot water, as well as for the decarbonisation of industry. The major challenge for the SES-2050 is therefore to have enough "doubly *neutral*" electricity available in winter.

This study explores the potential of the novel ULISSE system (*Under Lake Infrastructure for capture and Storage of Solar Energy*), as well as the possibility to be combined with the CORSAIRE "*free heating"* process (without heat pumps). ULISSE aims to improve the efficiency of the Thermal Lacustrine Networks (TLNs), to be potentially installed in the 15 major Swiss lakes, while providing advantageously deep oxygenation of said lakes, induced by external thermal convection of the ULISSE reservoirs. CORSAIRE free heating aims to reduce the negative energy impact on buildings caused by the winter drop in temperature of the public Drinking Water Network (DWN).

The ULISSE system concept consists of large seasonal heat storage reservoirs anchored to the lake bed (typical unit capacity: 2 million m^3 & 125 TJ). In summer, they are filled with temperate water, either from the upper layer of the lake heated by the sun, or from industrial and air-conditioning waste heat. The ULISSE reservoirs would constitute a source of winter heat from the lake water at around 20°C, instead of the usual 5-6°C. This can double the efficiency of the heat pumps and halves their electricity consumption, reducing the volume of water by a factor of 5 and the electrical energy required to pump and circulate the water in the TLNs by 95%.

The study provides an initial energetic potential and feasibility analysis of a possible structure (envelope, anchoring) for the ULISSE reservoir, a sketch of its thermal loading/discharging system and some hints regarding its potential interactions with the lake ambient (thermal, hydrodynamic, environmental). More specifically, a cross-study (with converging results) of the efficiency of the seasonal thermal storage of the ULISSE reservoir was also carried out, using three complementary approaches: the construction of a theoretical model, a mock-up with a fundamental analysis of the Temporal Scaling Factor, and a numerical simulation (COMSOL).

As a major example, the study analyses the overall energy performance of the ULISSE - CORSAIRE system applied to the GeniLac TLN and the DWN in Geneva, and compares it with the system for capturing and storing seasonal "terrestrial" solar heat (collector field + covered basin), then extrapolates it to the national scale.

As a result, and conclusion from the project, around 300 ULISSE reservoirs spread invisibly across the 15 major Swiss lakes and combined with CORSAIRE *free heating* (including outside the lake regions) could have the potential to supply almost 60 PJ or 30% of the 200 PJ of national energy-heat requirements for ambient heating and domestic hot water. For an overall investment estimated to around CHF 3 to 4 billion (ULISSE reservoirs, CORSAIRE heat exchangers, pipelines), this would save 3 TWh of gross electricity in the winter semester 2050, i.e., 1/3 of the 9 TWh winter electricity deficit and equivalent to twice the winter production of Switzerland's largest hydroelectric complex, Grande Dixence (2 x 1.5 TWh).

Finally, the study proposes a pilot ULISSE Reservoir, connected to the TLNs on the EPFL-UNIL campuses, with observations by the LéXPLORE floating laboratory as well as a pilot CORSAIRE in the Cité du Lignon (6,500 inhabitants and shops) and supplied with thermal waste from the Aïre wastewater treatment plant in Geneva.

Keywords: thermal lacustrine network, free cooling, free heating, seasonal sub-lacustrine heat storage, winter de-icing, temperature correction of drinking water network, heat pump, GeniLac, Geneva.

Résumé

Face aux changements climatiques la *Stratégie Énergétique Suisse* 2050 (SES-2050) vise la *« double neutralité » nucléaire & carbone* (2035-2050) et prévoit un déficit structurel en semestre hiver de 9 TWh d'électricité (équivalent à la capacité nationale d'accumulation hydroélectrique). Il résulte du retrait planifié de l'électricité nucléaire en 2035 et de l'augmentation de la demande d'électricité, pour la mobilité électrique, les pompes à chaleur (HP) pour la climatisation, le chauffage du bâti et l'eau chaude sanitaire, ainsi que pour la décarbonation de l'industrie. L'enjeu majeur de la SES-2050 est donc de disposer de suffisamment d'électricité « doublement *neutre* » en hiver.

La présente étude explore le potentiel du système inédit ULISSE (*Under Lake Infrastructure for capture and Storage of Solar Energy*) associé à la possibilité de combiner le procédé CORSAIRE « *free heating* » (sans HP). ULISSE vise à améliorer l'efficacité des Réseaux Thermo Lacustres (RTLs), potentiellement implantés dans les 15 grands lacs suisses, tout en induisant avantageusement l'oxygénation profonde desdits lacs par la convection thermique externe des réservoirs ULISSE. Le CORSAIRE free heating quant à lui vise à réduire l'impact énergétique négatif sur le parc immobilier induit par la chute hivernale de la température du Réseau public d'Eau Potable (REP).

Le système ULISSE est constitué de grands réservoirs de stockage saisonnier de chaleur ancrés sur les fonds lacustres (capacité unitaire : 2 millions m^3 & 125 TJ). Ils sont chargés en été d'eau tempérée, soit issue de la couche supérieure du lac chauffée par le soleil, soit par des rejets de chaleur industrielle et de climatisation. Les réservoirs ULISSE sont une source lacustre de chaleur hivernale d'eau à environ 20°C, au lieu d'ordinaire à 5-6°C. Ceci peut doubler l'efficacité des HP et diminuer de moitié leur consommation électrique, réduire d'un facteur 5 le volume d'eau et de 95 % l'énergie électrique de pompage et de circulation de l'eau dans le RTL.

L'étude réalise une première analyse du potentiel énergétique et d'une possible structure (enveloppe, ancrage) du réservoir ULISSE, l'esquisse de son système de chargement/déchargement thermique ainsi que ses potentielles interactions lacustres (thermiques, hydrodynamiques, environnementaux). Plus spécifiquement est aussi réalisé une étude croisée (aux résultats convergents) de l'efficacité du stockage thermique saisonnier du réservoir ULISSE, ceci par trois approches complémentaires : l'élaboration d'un modèle théorique, une maquette avec analyse fondamentale du facteur d'échelle temporelle ainsi qu'une simulation numérique (COMSOL).

À titre d'exemple majeur, l'étude analyse les performances énergétiques globales du système ULISSE - CORSAIRE appliqué au RTL GeniLac et au REP à Genève, les comparent au système de capture et de stockage saisonnier de chaleur solaire « terrestre » (champ de capteurs + basin couvert), puis l'extrapole à l'échelle nationale.

En résultat et conclusion du projet, environ 300 Réservoirs ULISSE répartis de façon invisible dans les 15 grands lacs suisses et en association avec le *free heating* CORSAIRE (y compris hors des régions lacustres) pourraient potentiellement fournir près de 60 PJ soit 30 % des 200 PJ des besoins nationaux d'énergie-chaleur pour le chauffage ambiant et l'eau chaude sanitaire. Pour un investissement global estimé à environ 3 à 4 milliards de CHF (réservoirs ULISSE, échangeurs de chaleur CORSAIRE, conduites), ceci permettrait d'économiser 3 TWh d'électricité brut en semestre d'hiver 2050 soit le 1/3 des 9 TWh de déficit hivernal d'électricité et équivalent au double de la production hivernale du plus grand complexe hydroélectrique suisse de la Grande Dixence (2 x 1,5 TWh).

Finalement, l'étude propose la réalisation d'un Réservoir ULISSE pilote. Celui-ci serait relié aux RTLs des campus EPFL-UNIL, avec observations par le laboratoire flottant LéXPLORE ainsi qu'un pilote CORSAIRE sur la Cité du Lignon (6'500 habitants et commerces) et alimentée avec les rejets thermiques de la Station d'épuration des eaux usées d'Aïre à Genève.

Mots-clefs : réseau thermo lacustre, free cooling, free heating, stockage saisonnier de chaleur sous-lacustre, déglaçage hivernal, correction température du réseau d'eau potable, pompe à chaleur, GeniLac, Genève.

Zusammenfassung

Angesichts des Klimawandels strebt die Schweizer Energie Strategie 2050 (SES-2050) eine "doppelte Neutralität" in Nuklear & Kohlenstoff (2035-2050) an und prognostiziert im Wintersemester ein strukturelles Defizit von 9 TWh Strom (entspricht der nationalen Speicherkapazität von Wasserkraft). Das Defizit resultiert aus dem geplanten Atomausstieg im Jahr 2035 und dem steigenden Strombedarf für Elektromobilität, Wärmepumpen (WP) für Klimatisierung, Gebäudeheizung und Warmwasserbereitung sowie für die Dekarbonisierung der Industrie. Die grosse Herausforderung für die SES-2050 besteht daher darin, im Winter genügend „doppelt neutralen“ Strom zur Verfügung zu haben.

Diese Studie untersucht das Potential des neuartigen ULISSE-Systems (*Under Lake Infrastructure for capture and Storage of Solar Energy*) sowie die Möglichkeit zur Kombination mit dem CORSAIRE " freie Heizung " (Prozess ohne WP). Ziel von ULISSE ist es, die Effizienz der Thermische Seenetzwerke (TSNs) zu verbessern, die möglicherweise in den 15 grossen Schweizer Seen installiert werden sollen, und gleichzeitig eine vorteilhafte Tiefensauerstoffanreicherung dieser Seen zu gewährleisten, die durch externe thermische Konvektion der ULISSE-Reservoirs induziert wird. CORSAIRE freie Heizung zielt darauf ab, die negativen Energieauswirkungen auf den Immobilienbestand zu reduzieren, die durch den winterlichen Temperaturabfall der Trinkwassernetze (TWN) verursacht werden.

Das ULISSE-System besteht aus grossen saisonalen Wärmespeicherreservoirs, die am Seeboden verankert sind (Einheitskapazität: 2 Millionen m^3 und 125 TJ). Im Sommer werden sie mit temperiertem Wasser gefüllt, entweder aus der von der Sonne erwärmten oberen Schicht des Sees oder aus Industrie- und Klimaanlagenabwärme. Die ULISSE-Reservoirs würden im Winter eine Wärmequelle aus dem Seewasser mit etwa 20 °C statt der üblichen 5-6 °C darstellen. Dadurch kann die Effizienz der Wärmepumpen verdoppelt und ihr Stromverbrauch halbiert werden, wodurch die Wassermenge um den Faktor 5 und die elektrische Energie, die zum Pumpen und Umwälzen des Wassers in den TSNs erforderlich ist, um 95 % reduziert werden.

Die Studie liefert eine erste energetische Potenzial- und Machbarkeitsanalyse einer möglichen Struktur (Hülle, Verankerung) für das ULISSE-Reservoir, eine Skizze seines thermischen Lade-/Entladesystems und einige Hinweise zu seinen möglichen Wechselwirkungen mit der Seeumgebung (thermisch, hydrodynamisch, umweltbedingt). Genauer gesagt wurde auch eine Kreuzstudie (mit konvergierenden Ergebnissen) der Effizienz der saisonalen Wärmespeicherung des ULISSE-Reservoirs durchgeführt, wobei drei komplementäre Ansätze zum Einsatz kamen: die Konstruktion eines theoretischen Modells, ein Modell mit einer grundlegenden Analyse von der zeitliche Skalierungsfaktor und eine numerische Simulation (COMSOL).

Als Beispiel, die Studie analysiert die Energieleistung des ULISSE-CORSAIRE-Systems, welches auf das TSN GeniLac und das TWN in Genf angewendet wird, und vergleicht sie mit dem saisonalen "terrestrischen" Solarwärmeerfassungs- und -Speicher System (Kollektorfeld + überdachtes Becken). Anschliessend wird es auf die nationale Ebene hochgerechnet.

Als Ergebnis und Fazit des Projekts könnten rund 300 ULISSE-Reservoirs, die unsichtbar über die 15 grossen Schweizer Seen verteilt sind, in Kombination mit der freien Heizung von CORSAIRE (auch ausserhalb der Seeregionen) das Potential haben, fast 60 PJ oder 30 % der 200 PJ des nationalen Energie-Wärme-Bedarfs für Raumheizung und Warmwasser bereitstellen. Bei einer geschätzten Gesamtinvestition von rund 3 bis 4 Milliarden Franken (ULISSE-Speicher, CORSAIRE-Wärmetauscher, Rohrleitung) würde dies im Winterhalbjahr 2050 3 TWh Bruttostrom einsparen, also 1/3 des Winterstromdefizits von 9 TWh. Das entspricht der doppelten Winterproduktion des grössten Wasserkraftwerks der Schweiz, Grande Dixence (2 x 1,5 TWh).

Schliesslich schlägt die Studie die Schaffung eines Pilot-ULISSE-Reservoirs vor, das mit den TSNs auf den EPFL-UNIL-Campussen verbunden ist, mit Beobachtungen durch das schwimmende LéXPLORE-Labor sowie eines Pilot-CORSAIRE der Cité du Lignon (6.500 Einwohner und Geschäfte), der mit thermischen Abfällen aus der Kläranlage Aïre in Genf versorgt.

Schlüsselwörter: Seewärmenetz, freie Kühlung, freie Heizung, saisonale Wärmespeicherung unterhalb des Sees, Winter Temperaturkorrektur des Trinkwassernetzes, Wärmepumpe, GeniLac.

Riassunto

Di fronte ai cambiamenti climatici, la Strategia Energetica Svizzera 2050 (SES-2050) punta alla "doppia neutralità" Nucleare & Carbone" (2035-2050) e prevede un deficit strutturale nel semestre invernale di 9 TWh di elettricità (equivalente di cahpità al fabbisogno nazionale accumulo idroelettrico). Deriva dal previsto ritiro dell'energia elettrica dal nucleare nel 2035 e dall'aumento della domanda di energia elettrica per la mobilità elettrica, le Pompe Di Calore (PDC) per la climatizzazione e il riscaldamento degli edifici, nonché per la decarbonizzazione dell'industria. La sfida principale del SES-2050 è quindi quella di avere abbastanza elettricità "doppiamente neutrale" in inverno.

Questo studio esplora le potenzialità del nuovo sistema ULISSE (Under Lake Infrastructure for capture and Storage of Solar Energy), nonché la possibilità di essere combinato con il processo di "free cooling" CORSAIRE (senza pompe di calore). ULISSE mira a migliorare l'efficienza delle Reti Termiche Lacustri (RTL), da installare potenzialmente nei 15 principali laghi svizzeri, fornendo vantaggiosamente un'ossigenazione profonda di detti laghi, indotta dalla convezione termica esterna dei serbatoi ULISSE. Il riscaldamento gratuito CORSAIRE mira a ridurre l'impatto energetico negativo sugli edifici causato dall'abbassamento della temperatura invernale della Rete pubblica di Acqua Potabile (RAP).

Il concetto del sistema ULISSE è costituito da grandi serbatoi di accumulo termico stagionale ancorati al fondo del lago (capacità unitaria tipica: 2 milioni di m3 e 125 TJ). In estate si riempiono di acqua temperata, proveniente dallo strato superiore del lago riscaldato dal sole, oppure dal calore di scarto industriale e dell'aria condizionata. Gli invasi dell'ULISSE costituirebbero una fonte di calore invernale proveniente dall'acqua del lago a circa 20°C, invece dei consueti 5-6°C. Ciò può raddoppiare l'efficienza delle pompe di calore e dimezzare il loro consumo di elettricità, riducendo di un fattore 5 il volume dell'acqua e del 95% l'energia elettrica necessaria per pompare e far circolare l'acqua nei RTL.

Lo studio fornisce una prima analisi di potenziale energetico e di fattibilità di una possibile struttura (involucro, ancoraggio) per il bacino ULISSE, uno schizzo del suo sistema di carico/scarico termico e alcuni cenni riguardanti le sue potenziali interazioni con l'ambiente lacustre (termico, idrodinamico, ambientale). Più nel dettaglio, è stato effettuato anche uno studio trasversale (con risultati convergenti) dell'efficienza dell'accumulo termico stagionale del giacimento ULISSE, utilizzando tre approcci complementari: la costruzione di un modello teorico, un mock-up con un'analisi fondamentale delle il fattore di scala temporale e una simulazione numerica (COMSOL).

Lo studio analizza le prestazioni energetiche del sistema ULISSE - CORSAIRE applicato al RTL Genilac e al RAP di Ginevra, confrontarli con il sistema stagionale di cattura e accumulo del calore solare "terrestre" (campo collettori + bacino coperto), poi lo estrapola alla scala nazionale.

Come risultato e conclusione del progetto, circa 300 bacini idrici ULISSE sparsi invisibilmente nei 15 principali laghi svizzeri e combinati con il riscaldamento gratuito CORSAIRE (anche al di fuori delle regioni lacustri) potrebbero avere il potenziale di fornire quasi 60 PJ o il 30% dei 200 PJ del fabbisogno energetico-termico nazionale per il riscaldamento ambientale e l'acqua calda sanitaria. Con un investimento complessivo stimato tra i 3 e i 4 miliardi di franchi (bacini ULISSE, scambiatori di calore CORSAIRE, tubazioni), si risparmierebbero nel semestre invernale 2050 3 TWh di elettricità lorda, ovvero 1/3 del deficit invernale di 9 TWh di elettricità e equivalente al doppio della produzione invernale del più grande complesso idroelettrico della Svizzera, Grande Dixence (2 x 1,5 TWh).

Infine, lo studio propone un bacino pilota ULISSE, collegato ai TLN dei campus EPFL-UNIL, con osservazioni del laboratorio galleggiante LéXPLORE e di un CORSAIRE pilota in la Cité du Lignon (6.500 abitanti e negozi) e alimentato con i rifiuti termici dell'impianto di depurazione dell'Aïre a Ginevra.

Parole chiave: rete termale lacustre, free cooling, free heating, accumulo di calore sublacustre stagionale, correzione della temperatura invernale della rete di acqua potabile, pompa di calore, GeniLac, Ginevra.

Foreword

As an innovative and unconventional project (Outside-the-box), the present study (***Under Lake Infrastructure for capture and Storage of Solar Energy***) explores novel concepts in their realizations, which requires substantial explanations and argument developments.

The present final report is a summarised version of an extended report, written in French, where further details can be found. This explains the use of French e.g., in some figures in the present report. Both the French extended report and its English translation are appendices to this final report and available on Aramis.

Acknowledgements

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"The Solution of the Pollution is NOT the Dilution"

Lucien Borel, Professor of Thermodynamics at EPFL from 1954 to 2007

1 Introduction

1.1 Context and state of the art of research

Faced with climate change, the SES-2050 aims for “carbon neutrality” by 2050 and “nuclear neutrality” for 2035. [1] Its largely based on improving the energy efficiency of buildings with generalized use of heat pumps (HP), for room heating (RH), the production of domestic hot water (DHW) as well as for cooling purposes and air conditioning (CAC).

As show on Figure 1 below, despite the planning of a massive development of renewable energies (584 PJ/y), with the significant need for electricity for heat pumps (19 TWh/y), to which must be added the mobility electrification (20 TWh/y), the planned shutdown of nuclear power (-20 TWh/y) and the decarbonation of industry, **a structural winter deficit of 9 TWh of electricity is expected in 2050**.

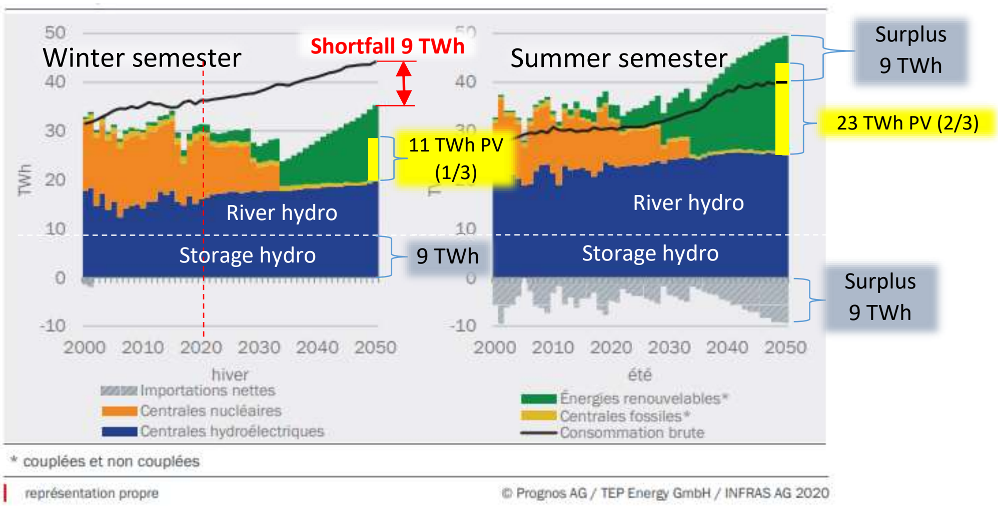


Figure 1: Development of gross electricity production during the winter and summer months in the ZERO-baseline scenario, "balanced annual balance" strategic variant in 2050, in TWh (source: SFOE EP2020+)

An increased annual production of undifferentiated electricity would be a “headlong rush”:

- Even more photovoltaics at the 34 TWh electricity already planned for 2050, to naturally only have 30% of annual production in the winter semester, would increase the risk of having to resort to the paradoxical "solar peak shavings" in summer. [17.2]

- Further development of hydroelectric storage capacity is limited by acceptable potential sites. Added to this is the problem of summer loading of dams under water stress due to Global Warming. The requirement for increased “residual water flows” (for fish and biodiversity protection) will further reduce hydropower productivity. The development potential by 2050 of an annual hydroelectricity production is 1 to 3 TWh (equivalent to the Grande Dixence complex), except that the availability in the winter semester is only half at best. i.e., around 1.5 TWh.

- Maintaining nuclear energy would accentuate water stress on waterways already impacted by Global Warming. For technical and economic reasons, a nuclear power plant generally operates in "ribbon" all year round (base load), therefore also in the summer semester. [18, 19] The Swiss nuclear power plant in Leibstadt, during the summer semester, releases in the form of water vapor 14 million m³ extracted from the Rhine River (32 PJ of heat equivalent to its annual electricity production of 9 TWh). The Gösgen nuclear power plant is not to be outdone with nearly 10 million m³ of water evaporated from the Aare River at the same time.

With the increase in summer drought, further exacerbated by more recurrent heat waves, the increased water needs for other uses, including agriculture in particular, will become even more critical. Consequently, thermoelectric power stations (nuclear, coal, fuel oil or gas) which cannot operate without loss of cooling water, will be forced to stop or reduce strongly their production in the summer semester and will therefore no longer be economically "competitive" and a fortiori no longer present in the winter semester. France and Germany, our main importers of winter electricity, have the same problem and climate commitment as Switzerland...

Development of thermal networks: one of the Spearheads of the SES-2050

The SES-2050 foresees for the massive development of thermal networks, for medium and large urban agglomerations, supplied with renewable energies and waste heat [14]. The thermal needs, for RH and DHW, is estimated at 200 PJ/year in 2050. [1.2] The thermal potential of lakes and that of wastewater treatment plants (WTP) together represent 40% of the needs for future thermal networks. [4, 13] In this context, a number of low temperature Thermal Lacustrine Networks (TLN), for “cold” and “hot” needs, are under construction. [8-11]

Relevance of developing Thermal Lacustrine Networks (TLN)

A quarter to a third of the Swiss population (≈ 10 M @ 2050) is located near the 15 largest Swiss lakes and could potentially be connected to a TLN network. The total "final" heat demand around the lakes is estimated at 25 PJ of cold and 135 PJ of heat, i.e., nearly 1/3 of the current national needs (70 PJ of cold & 360 PJ of heat in 2020). [27]

Illustrated in Figure 2 below, the cooling and heating of buildings near the lakes requires TLNs, to capture the "heat carrier" water, transport it and distribute it to the urban agglomerations and finally in closed loop return it to the lakes.

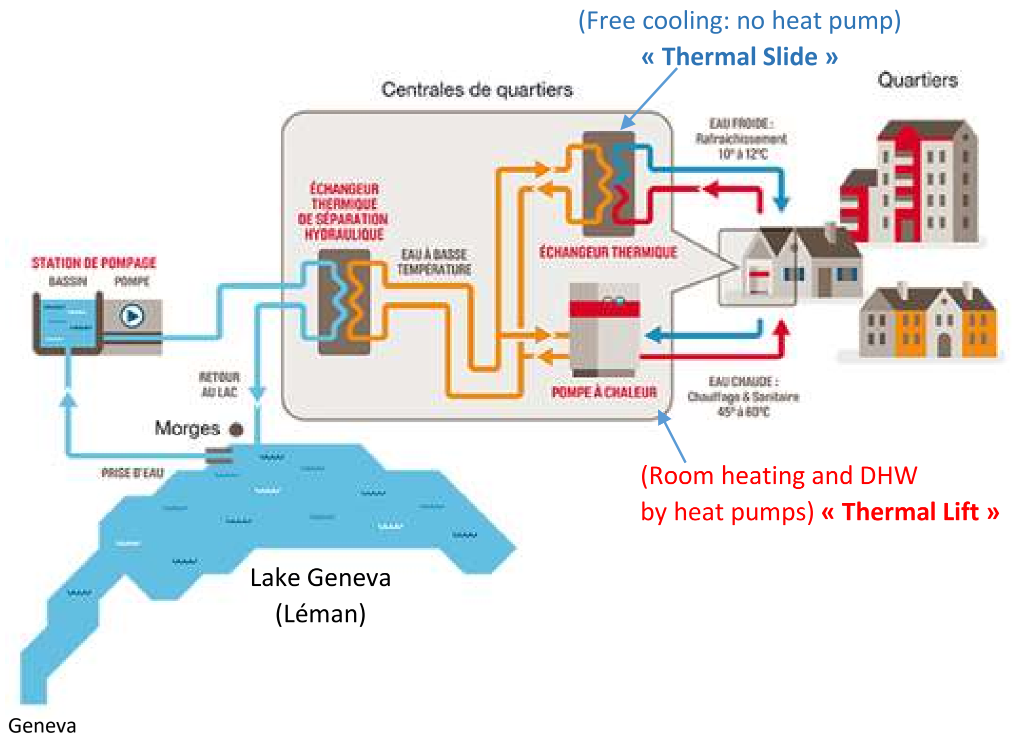


Figure 2: Example of a Thermal Lacustrine Network (TLN) with MorgesLac in the town of Morges (VD)

Seasonal energy performances of the TLNs

On the one hand, TLNs such as those on Lake Geneva (GLN-GeniLac in Geneva, MorgesLac, EPFL-UNIL, etc.), are very effective for summer air conditioning in "free cooling" (without HP), this with cold water (5-7°C) pumped from the bottom of the lake (hypolimnion zone) and acting as a real "thermal toboggan". The electrical coefficient of performance (COP) of TLNs can reach 18 (GeniLac forecast of SIG), i.e., 5.5% of electricity to introduce into Lake Geneva the energy-heat extracted from buildings in summer (compared to a COP ≤ 3 for a conventional air conditioner).

On the other hand, the winter heating of buildings is 4 to 5 times less efficient than the said summer air conditioning in free cooling. This by the inevitable use of heat pumps to raise the useful temperature like a "thermal lift" (for RH & DHW) but also by a lower temperature difference (ΔT) round trip usable from the lake water, which contributes to and increases the winter electricity consumption of TLNs [7-11, 58, 59]. There is a potential for improvement which the present project aims at investigating with its proposed new concept.

Environmental limits of the thermal exploitation of lakes

Due to global warming, the surface temperature of our lakes has increased by about two degrees over the past 40 years. Because of less cold winters, warmer surface waters reduce the depth of annual water mixing and therefore the vital oxygenation provided to aquatic life. [27]

If the thermal potential of lakes exceeds local needs by several times, in order not to further impact the aquatic ecosystem, lake thermal use is limited and regulated (ordinance), mainly regarding the depth and the water intake and return temperature.

The limitation avoids increasing the thermocline (thermal transition zone) by heating the surface layers (epilimnion zone) in summer, due to air conditioning, or cooling the deep layers (hypolimnion) in autumn and winter (for the needs of RH and DHW), which can ultimately delay/prevent said water layer mixture favourable to reoxygenation and the circulation of nutrients. [27, 31]

Origin of the ULISSE and CORSAIRE projects & state of the art

- The CORSAIRE process was the subject of the author's master thesis at EPFL (1995). It dealt with the recovery of waste heat from CERN (700 GWh-t or 2,5 PJ) in the winter correction (5 to 10°C) of the temperature of the (existing) public drinking water network (DWN) in the canton of Geneva. [43] Without seasonal heat storage, this implied that these waste heat has mostly produced and available during the winter semester and therefore the constraining displacement in summer of the annual "shut down" of CERN's accelerators and experiments.

- As an alternative, the author had then proposed an additional device for Seasonal Lacustrine Heat Storage making it possible to recover the heat of the cooling water from CERN during the summer semester to valorise it during the winter semester (when CERN is normally in shut down). As a precursor to the ULISSE project, (Figure 3 below), the author presented this expanded concept at the 10th General Conference of the European Physical Society (EPS 10 *Trends in Physics*) in Sevilla, Spain, September 1996. [44]

  The original master thesis (EPFL 1995) shows that the CORSAIRE free heating can potentially reduce the *heat demand index* (HDI), for RH & DHW of residential buildings on the scale of an (entire) city by up to 10%; this in the current state of their energy efficiency and without any intervention or additional equipment on the buildings! [65]

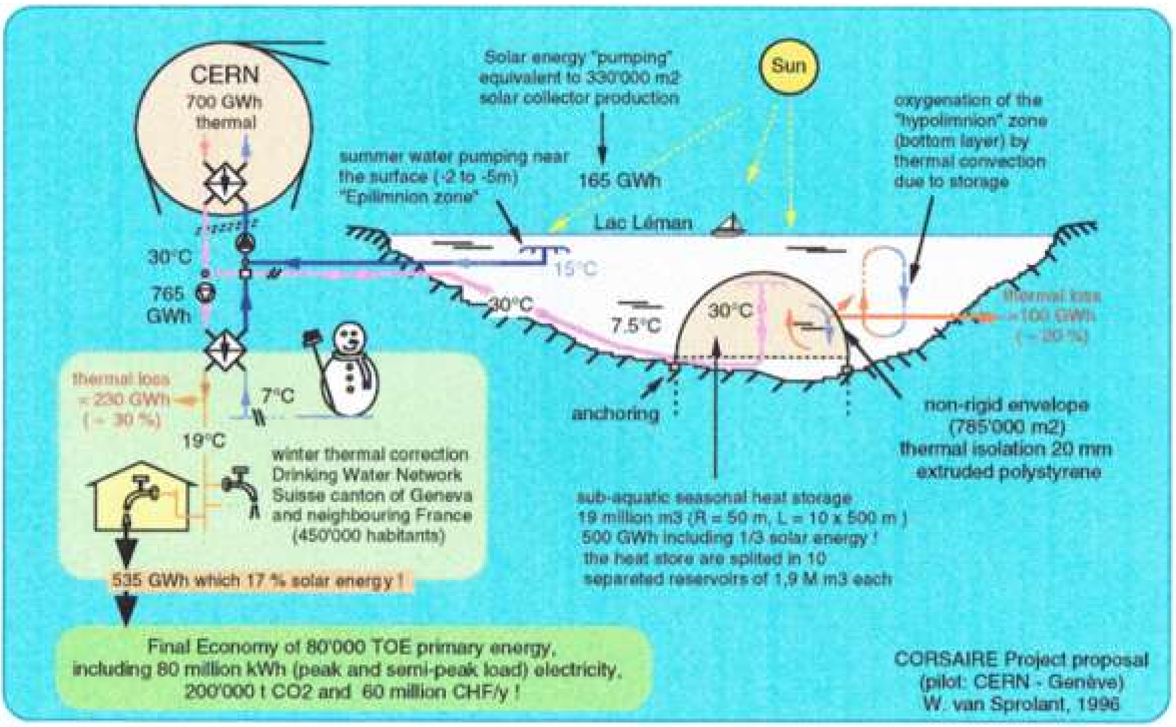


Figure 3: Addition of the seasonal lacustrine storage reservoir for CERN's thermal waste (EPFL master's thesis 1995) Contribution on the 10th General conference of the European Physical Society, Sevilla 1996

- Under the impulse of the Cantonal Energy Office (OCEN), the CORSAIRE project is included in the Energy Master Plan of the canton of Geneva (2001-2005) and in November 2005, under the supervision of the initial author of the project and financed by the OCEN, begins part -1 of the multidisciplinary impact study on a pilot residential building made available by the City of Geneva. [46] Unfortunately, 3 months after its start, it was abruptly stopped, on the grounds of an unforeseen budgetary restriction of the OCEN! And since then, the project has not been reconsidered despite Geneva's ambitious energy objective at the time (2'000 W society without nuclear power by 2050)!

- In the meantime, since 2006, a principle similar as the CORSAIRE free heating has been used in the Canadian city of Toronto (3 million inhabitants, eq. 1/3 of Switzerland) with its "Deep Lake Water Cooling" (DLWC) network. With a cooling capacity of 360 MW, the thermal energy extracted from the air conditioning of the buildings is injected into Toronto's public drinking water network via a battery of heat exchangers (Figure 4 below), exactly like the CORSAIRE free heating process, but inversely in summer! [51, 52, 53]

  The Toronto DLWC with Lake Ontario has one of the world's largest thermal lake air conditioning systems. Similar to the TLN GeniLac network in Geneva, thanks to the free cooling, it saves 90 GWh of electricity and 1 million m^3 of water annually, compared to compression and waste water refrigeration machines (saving of electricity ≈ 80%, source Enwave). [51,52,53] However, in the opposite season of the CORSAIRE free heating applied in the winter semester, the heat from the DLWC system's is used to "deglaze" ($\Delta T \approx 8$ K) 1/4 of the city's drinking water network in the summer and finally avoids dumping the waste heat from the air conditioning into Lake Ontario.

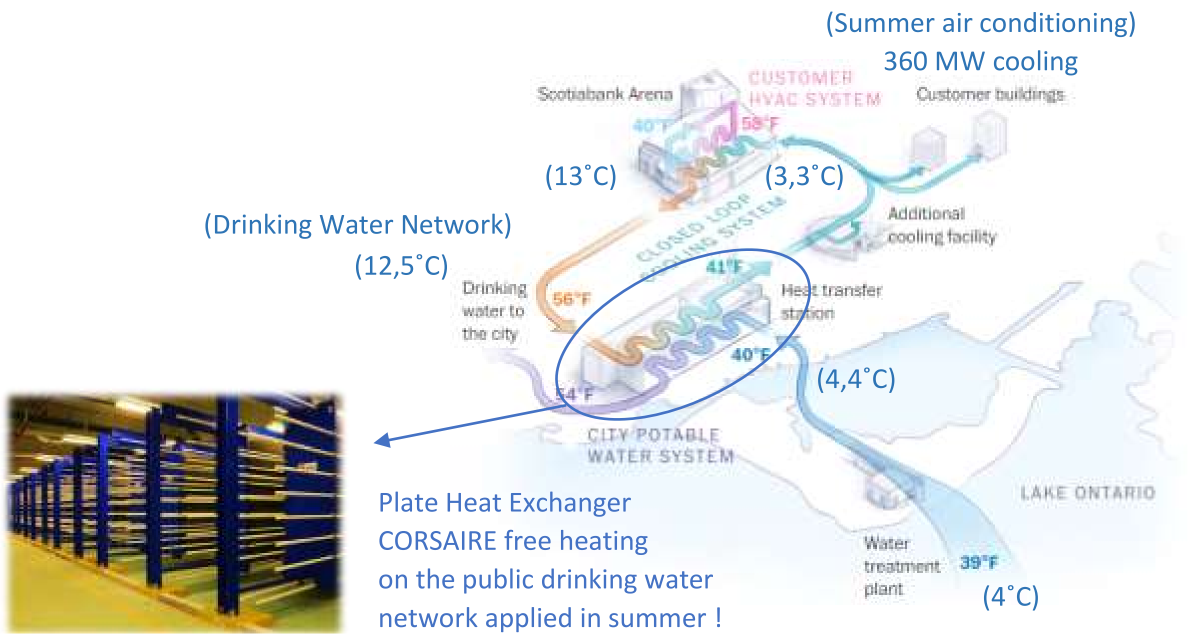


Figure 4: Schematic diagram of the deep lake water cooling system in Toronto (DLWC), with thermal energy injected into the public drinking water network via a heat exchanger (source: Enwave, Washington Post)

Precursor of a floating lake thermal reservoir

In 1980 the Swedish designer P. Margen suggested a hot water tank (90˚C) floating on the surface of a lake or the sea (Figure 5 below). This tank consists of a thermally insulated rigid box, open at its base and fitted with floating pontoons, all firmly secured with cables to anchor blocks. The caisson emerges as an iceberg variably above the surface of the water body depending on the quantity and temperature of the water in the caisson (0.5 m at 90˚C). [36, 37]

Ignoring if there are some existing applications, the potential implementation sites are most likely limited. Not only would local residents not appreciate the visual impact in the landscape, but in addition, this device emerging from the water like an iceberg in a variable way would constitute an unacceptably high danger for navigation. In addition, this floating structure would be subject to the eddies of the waves which can destabilize and tear everything apart in the event of strong winds or storms (the waves in Lake Geneva can reach hollows of 2 m).

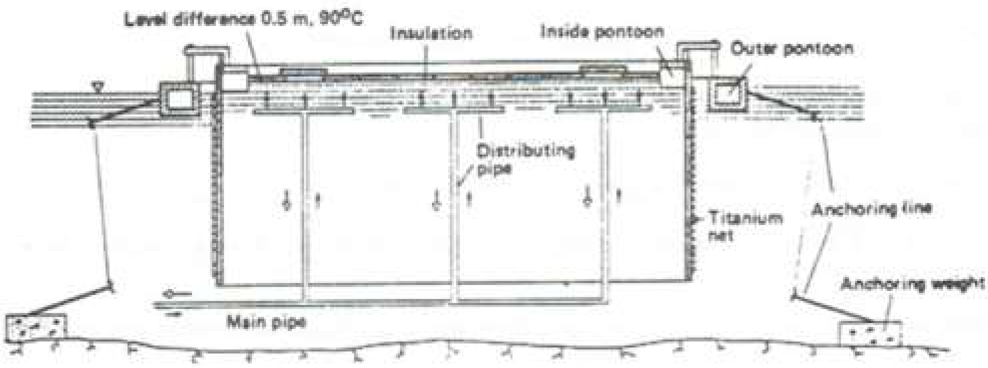


Figure 5: Swedish designer P. Margen's proposal for a floating hot water tank (1980), Source: SIA OFEN 1987, Guide to Seasonal Heat Storage, J-C. Hadorn [37]

The establishment of such a structure, which can only be done with difficulty in deep seas, would be confined in a prohibitive way, in the coastal or littoral zone where a large part of the flora (herbariums) and lake fauna is located. These would be in potential direct contact with hot water, which could be expelled from the box under the eddies and movements generated by strong winds.

To the author's knowledge, there is therefore no equivalent concept for a system with the capacity and potential benefits equivalent to those proposed in this ULISSE project.

1.2 Unconventionality and originality of the project

This study proposes and explores the original ULISSE system concept associated with the CORSAIRE "free heating" (process without HP). ULISSE aims to optimize the development of the TLNs to be potentially implemented in the 15 largest Swiss lakes. Moreover, the project proposes that the implementation of such concept could contribute to protect lakes against global warming by taking advantage the thermal convections induced by the heat losses of the ULISSE Reservoirs.

The project also studies a coupling with the so-called CORSAIRE free heating concept [reference to master thesis where it was developed], in order to reduce the negative energy impact on the building stock induced by the circulation of cold water during the winter in the public drinking water networks (DWNs).

The proposed ULISSE system consists of large seasonal heat storage Reservoirs anchored to the lake bottoms, as a unique solution, without floor space use, of unprecedented storage capacity of 2 million m^3 of warm water per individual reservoir for 125 TJ equivalent of heat.

The Thermal Lacustrine Network booster

The ULISSE system first aims to overcome the limitations of TLNs. First, the ULISSE Reservoirs would represent a lacustrine source of winter heat of around 20°C, whereas it is ordinary at 5-6°C. The project demonstrates that this would double the heat pumps efficiency or halve their electricity consumption and reduces the pumped volume of water by a factor of 5, and hence reduce by 95% the electrical energy for pumping and circulating the water in the said TLN networks.

The CORSAIRE free heating

The second way of using the temperate water provided by the ULISSE Reservoirs or other thermal discharges is to correct (5 to 10˚C) the winter drop in temperature of the public DWN by the CORSAIRE process of free heating (without heat pump). Illustrated on Figure 6 below, all DWNs are potentially affected by free heating which can provide 30% of the heat for DHW, reduce the electricity consumption of connected washing machines/dishwashers and increase the general electrical efficiency of TLNs. [42 to 52]

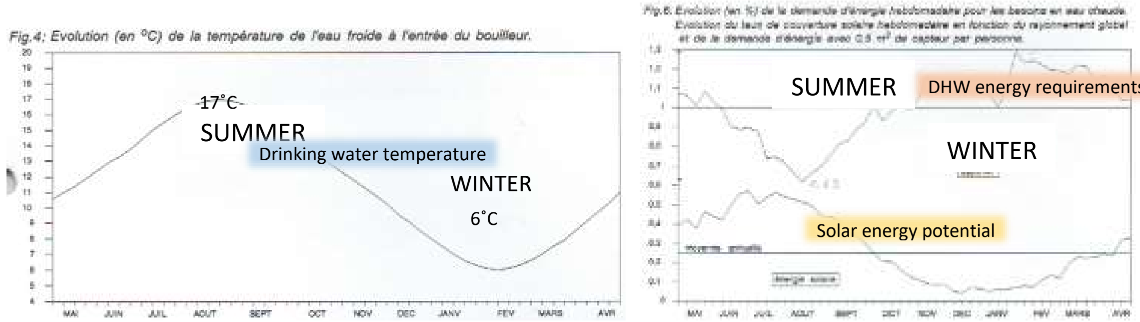


Figure 6: Seasonal evolution of the cold-water temperature at the building entrance (Fig. left) and of the energy requirement (Fig. right), for domestic hot water (DHW), measured on several rental buildings (1000 dwellings), for the evaluation of solar installations for DHW preheating. Ville de Genève / Service de l'Energie, June 1990. [43, 46]

2 Objectives

The 3 main objectives of the ULISSE concept associated with CORSAIRE are:

- Improve (boost) the electrical efficiency of TLN networks potentially located in the 15 largest Swiss lakes,
- Provide a solution to help protect the lakes against effect of Global Warming using ULISSE Reservoirs,
- Reduce the negative energy impact of the winter temperature drop in the public DWN (CORSAIRE free heating).

The study carries out an initial development and analysis of a possible structure (envelope, anchoring) of the ULISSE Reservoir, of the outline of its thermal loading and unloading system, as well as a reflection on its potential lake interactions (thermal, hydrodynamic, environmental). A cross-study (with convergent results) of the seasonal thermal storage efficiency of the ULISSE Reservoir is thus carried out using three complementary approaches: theoretical model, Mock-up with fundamental analysis of the temporal scale factor as well as a numerical simulation (COMSOL).

As a major example, the study analyses the global energy performance of the ULISSE - CORSAIRE system applied to the TLN GeniLac and the DWN in Geneva, compare them to a seasonal "terrestrial" solar heat capture and storage system (collector field + covered basin); then extrapolates it to the national scale.

About 300 ULISSE Reservoirs distributed invisibly in the 15 large Swiss lakes and in association with the CORSAIRE free heating exchangers (including outside the lake regions) could provide nearly 60 PJ or 30 % of the 200 PJ of the national needs of heat energy for room heating and domestic hot water. For a total investment of around 3 to 4 billion CHF (ULISSE Reservoirs, CORSAIRE heating exchangers, pipes), this would save 3 TWh of gross electricity in the winter semester, i.e., 1/3 of the 9 TWh winter electricity deficit, equivalent to twice the winter production of the largest Swiss hydroelectric complex of Grande Dixence (2 x 1.5 TWh).

Finally (Next step), the study proposes to create a pilot ULISSE Reservoir, connected to the TLNs of the EPFL-UNIL campuses with observations by the LéXPLORE floating laboratory, and a P+D CORSAIRE on the *Cité du Lignon* (6,500 inhabitants and shops) and supplied with residual heat from the waste water treatment plant of Aïre in Geneva.

3 Results and discussion

Organisation of the ULISSE exploratory study and approaches:

As part of the SFOE's SOUR programme, the exploratory study of the ULISSE project carried out at HEPIA includes the following points:

- Structural study, material composition and operation of the ULISSE Reservoir,
- Carrying out resistance tests on cellular glass (FOAMGLAS) under hydrostatic pressure,
- Energy analysis of the ULISSE - CORSAIRE combined system on the GeniLac TLN and Geneva's DWN,
- Extrapolation of GeniLac results to the national level,
- Technical and economic comparison with alternative thermal networks, fed by solar thermal collectors and an earth basin for seasonal heat storage,
- Exploring the potential environmental impacts of lakes hosting ULISSE Reservoirs.

More specifically, establishing the seasonal storage efficiency of the ULISSE reservoir involves the following points:

- Analysis of the heat transfer coefficient of the ULISSE Reservoir shell,
- Creation of an experimental Mock-up to reproduce the various operating phases,
- Establishment of *the Temporal Scale Factor (TSF)* between the real full-scale Reservoir and the reduced-scale Mock-up.

In addition, heat losses are calculated using 3 complementary approaches:

- Calculations based on a simplified theoretical model of the Mock-up and the full-scale Reservoir,
- Calculations based on data acquired by the Mock-up experiment,
- Numerical simulation (COMSOL Multiphysics) of the Mock-up and the full-scale Reservoir.

Part A: Technical and energy considerations

3.1 The ULISSE Reservoir concept

3.1.1 Overall design

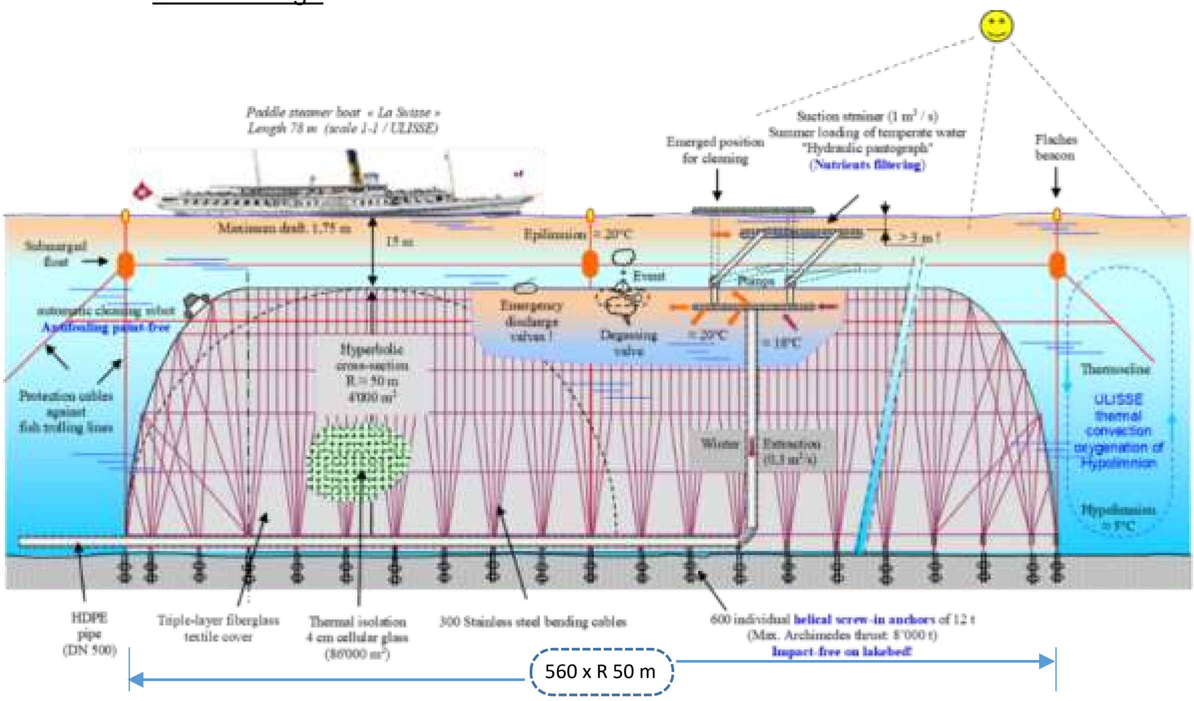


Fig.7: Truncated longitudinal diagram of a typical ULISSE Reservoir of 2 M m³ (CGN boat to same scale)

Illustrated in Figure 7 above, the proposed ULISSE heat source consists of several large "tunnel" Reservoirs (length 560 m x 50 m of hyperbolic transverse radius), anchored on the lake bottoms, with a unit storage volume of 2 million m³ and a thermal capacity of 125 TJ each. These ULISSE Reservoirs are charged in summer with temperate water, either from the upper layer of the lake (epilimnion) heated by the sun, or by industrial and air conditioning waste heat. The loading pumps are powered by photovoltaic electricity absorbing the summer production peaks of photovoltaic installations and avoids the use of said PV peak-shavings. [17.2]

3.1.2 Anchoring

The lower edges of the transverse bands of the envelope also adopt a hyperbolic shape by the tension of a stainless-steel cable which is held by a similar jaw hooking system. We propose to connect the cables to the 515 low-impact screw-in helical anchors on the bottom of the lake (Marine Flex Screw Anchor Technology, Fig. 8 below). This lower part of the envelope is covered with a fiberglass textile skirt, a priori uninsulated, touching the lake bottom and closing the access to the Reservoir for the local fauna.

Archimedes' upward thrust, which the anchoring must at least retain 7 k t. It results, for the constant half, from the apparent density of the insulation of the envelope (-835 kg/m³) and, for the variable half, from the quantity as well as the temperature of the "hot" water in the Reservoir (-1.76 kg/m³ @ ΔT: 15 K).

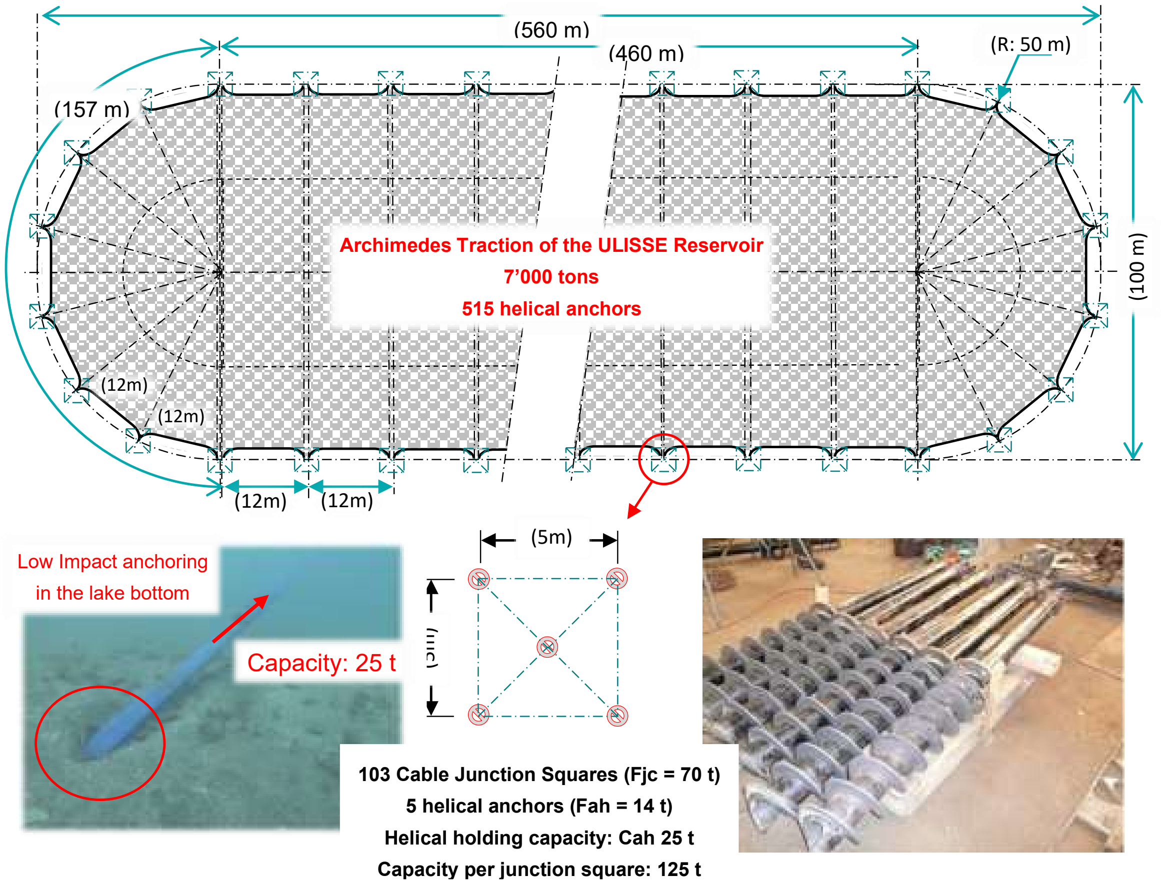


Fig. 8: Principle of anchoring the ULISSE Reservoir on the lake bottom with Marine Flex helical screw anchors

3.1.3 ULISSE lake water collector and storage device

The ULISSE Reservoir is in the summer period thermally loaded (SL), either by capture of temperate water from the upper layer (epilimnion zone) heated directly by the summer sun, or by a dedicated network of industrial waste heat discharges (i.e., Waste water Treatment Plant, WTP) or via the TLN from air conditioning (indirect solar heat).

Illustrated in Figure 9 below, the mobile lake water collector device consists of a suction strainer, divided into two parts (A-B). The tubular Strainer is adjustable in height (3 to 15 m from the surface of the lake) by the joints of the connecting pipes to the pumps. These are placed at the top of the Reservoir and connected to the temperate water injection/extraction ramp. The top of the Reservoir is located at a depth of about ten meters below the draft of the boats which can pass over it without others.

Each part A/B of the strainer is fitted with a grid and a micro-organism filter (phytoplankton). The filter is retractable by remote control allowing it to be placed in front of the suction openings and thus to regulate, if necessary, the quantity of phytoplankton captured per unit volume of water sucked up. Dead and settled phytoplankton on the lake bottom are decomposed by bacteria producing mainly carbon dioxide (CO_2) and methane gas (CH_4). These are collected in the ULISSE Reservoir for energy use.

The articulated pipes form a deformable parallelogram (hydraulic pantograph) which keeps the mobile strainer in a horizontal position whatever its height facing the lake water body and allows the strainer to be taken above the water surface for repair or maintenance. A plug for the injection/extraction rail orifices allows periodic counter-current self-cleaning and alternating between the two strainer compartments.

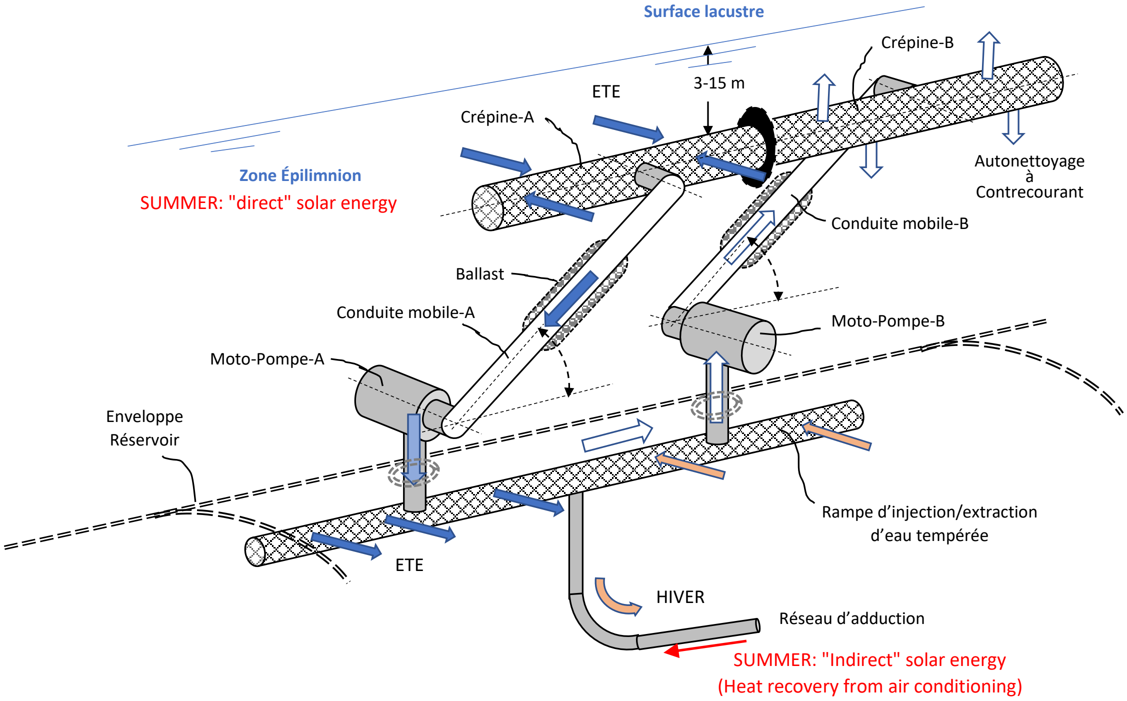


Figure 9: Schematic diagram of the mobile temperate lake water collection device (Epilimnion zone) Here the internal injection/extraction manifold is closed during the strainer self-cleaning process. The water sucked into the A-strainer is pumped back to the B-strainer for counter-current cleaning and vice versa.

3.1.4 Reservoir operation (Loading & Discharging cycles)

Operation of the Reservoir consists of an annual cycle of 4 distinct (seasonal) phases of different durations, comprising: 1 *Summer Loading of* tempered water (SL), 2 *Autumn Stagnation of* the full Reservoir (AS), 3 *Winter Discharging* (WD) of tempered water, 4 *Spring Stagnation* (SS) of the "thermally empty" Reservoir. The durations of the various phases of annual operation influence the energy balance and are shown in Figure 10 below:

1. Summer Loading (SL) => 2 months (6h/day)
2. Autumn Stagnation (AS) => 2 months
3. Winter Discharging (WD) => 6 months
4. Spring Stagnation (SS) => 2 months

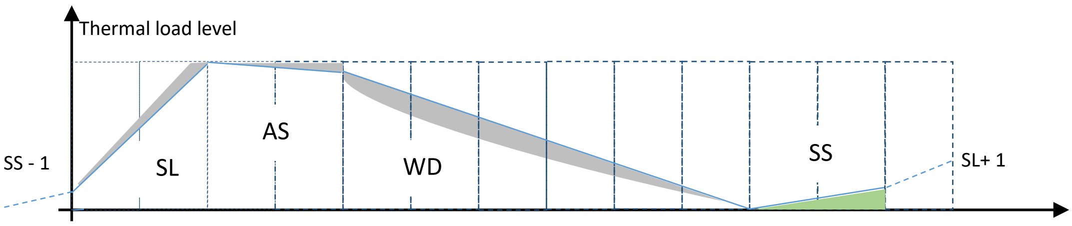


Figure 10: Dynamic operating phases of the ULISSE Reservoir (annual cycle)
*(Grey areas: **loss/gain**)*

3.1.5 Envelope

The ULISSE Reservoir consists of a semi-rigid/flexible domed shape envelope with the opening facing downwards and fixed near the lake bottom by means of non-invasive Screw-in anchors. The Reservoir envelope is provided with thermal insulation consisting of cellular glass blocks. Cellular glass has a low density (100 to 200 kg/m^3), resists a hydrostatic pressure of 10 kg/cm^2 and is totally hydrophobic. These "pavers" reduce heat loss and ensure, by their low-density facing water, the essential structural stability of the self-supporting ULISSE Reservoir even when it only contains cold water identical to that surrounding the lake!

Illustrated in Figures 11 and 12 below, the juxtaposed and independent rigid blocks are required to give the overall mobility (semi-rigid/flexible) and the shape of the envelope of the Reservoir. The pavers follow the curvature of the envelope (R ≈ 50 m) and have between them a variable inclination of a few degrees. Despite a thickness of the pavers of a few centimetres (≈5 cm), heat loss is limited (15-20%), by the favourable ratio between the surface of the envelope (88,000 m^2) and the large volume of the Reservoir (2.10^6 m^3). The envelope is made up of a triple layer of technical textile, in type E fiberglass. The insulation blocks (paves) are "sandwiched" between the outer layer of textile and the inner layer. The paves are held in place (against the upward thrust of Archimedes) by an intermediate layer of textile.

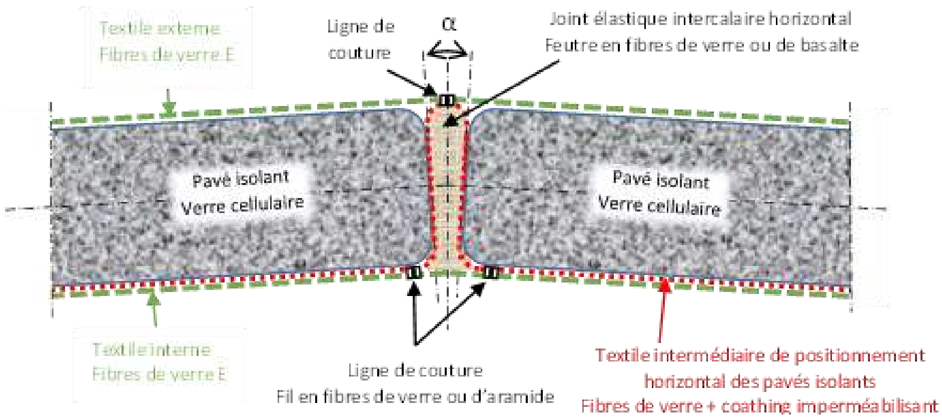


Figure 11: Cross-section of the ULISSE Reservoir shell (junction of insulating blocks)

Pads of fiberglass or basalt needled felt are interposed between said blocks. They reduce heat loss and water leakage at the interfaces. The latter is caused by the difference in hydrostatic pressure of the hot water under the envelope and can be eliminated by waterproofing the intermediate textile. In addition, the permeable layers of textiles are hydraulically obstructed by the cellular glass pavers. Illustrated in Figure 12, wide bands of transverse arches of the envelope (≈ 10 m) are interconnected by clamping in symmetrical junction jaws. The steps are covered with an insulating felt quilted mattress.

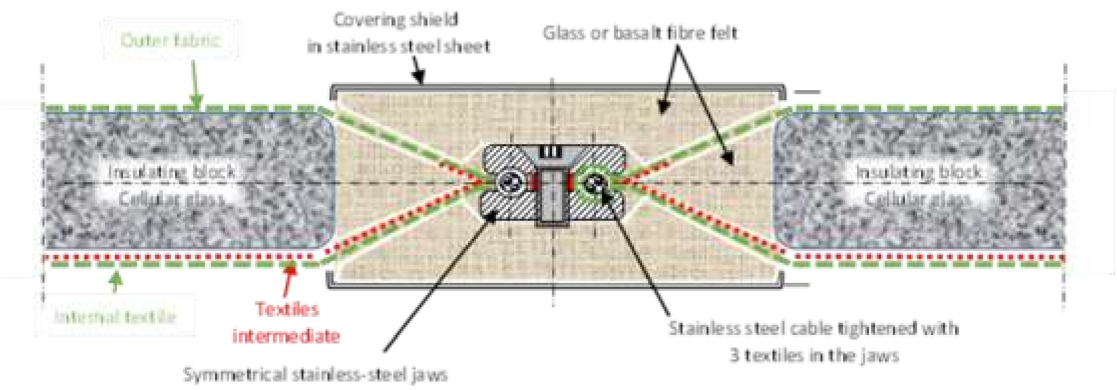


Figure 12: Junction principle of the transverse bands of the ULISSE Reservoir shell

3.1.6 Hyperbolic transverse shape of the ULISSE Reservoir

The envelope of the ULISSE Reservoir is fitted with thermal insulation slabs of cellular glass approximately 5 cm thick. The low density of cellular glass (ρi = 165 kg/m³ for e.g., Pittsburgh Corning's FOAMGLAS-F), immersed in water (ρe ≈ 1'000 kg @ 20˚C), represents an apparent density (Δρi) of approximately (-) 835 kg/m³, which generates a volumetric (upward) Archimedean force (Fai), uniformly distributed over the said envelope.

$$Fai = \Delta\rho i = \rho i - \rho e = 165 - 1'000 = -835 \quad [kg/m^3] \qquad (1)$$

Illustrated in Figure 13 below, this volumetric force (Fai) gives the characteristic "hyperbolic" transverse curvature of the envelope. By analogy, it is also the (inverted) shape taken by a chain suspended by its ends under the effect of gravitational gravity.

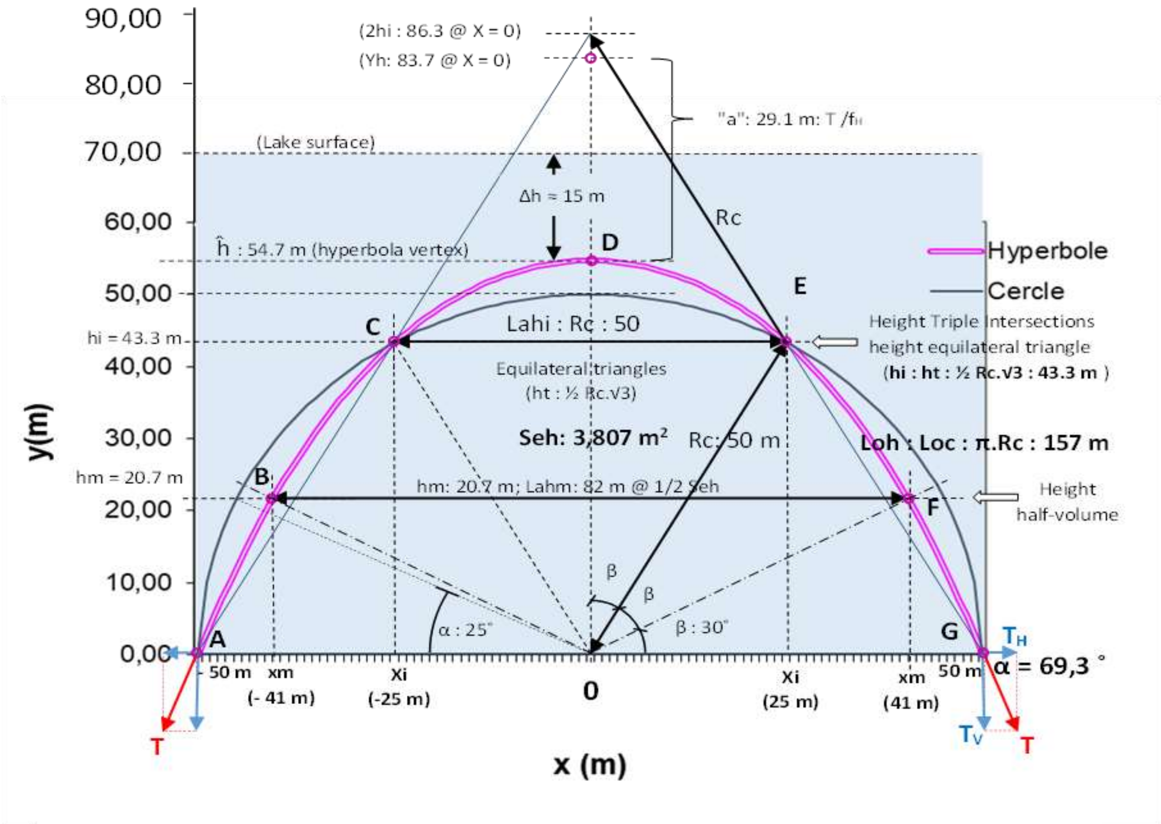


*Figure 13: **Hyperbolic** transverse curvature of the envelope compared with the arc of a circle*

The apparent density of the insulation (Δρi: - 835 kg/m³), with insulation volume (Vi: 4,388 m³), generates a constant tensile force on the envelope of 3,664 tonnes. Added to this is the difference in water density, between that of the Reservoir (V: 2 10^6 m³) and that of the lake, linked to their temperature difference (ΔT) and which varies according to the "thermal load". With a maximum ΔT of 15 K, the density difference is -1.76 kg/m³ and generates an additional Archimedean force on the envelope of 3,520 tonnes. Archimedes' thrust then totals a maximum of nearly 7,000 tonnes, which the envelope and anchorage of the ULISSE Reservoir must withstand.

This difference in water density generates a hydrostatic pressure which is a function of the height of the hot water column in the Reservoir. It increases towards the top and depends on the thermal filling of the Reservoir. The curve of the envelope then approaches "linear", or the so-called "bachette" curve (by analogy with the hyperbolic catenary), and whose curvature is proportional to the height and temperature of the hot water in the Reservoir.

3.1.7 Properties of the constituent materials of the ULISSE Reservoir envelope

The elements constituting the envelope (textiles, insulation, cables, junction pieces, etc.) must meet multiple technical and environmental criteria: thermal insulation capacity, self-supporting, resistance to hydrostatic pressure (insulation), to traction and flexibility (textiles, cables), hydrophobic, vapor-tight, stainless, rot-proof, biocompatibility, embodied energy and minimal GHG emissions during manufacturing, recyclable (circular economy). To do this, the structure of the envelope is made up of 3 layers of E-glass fiber textiles which contain cellular glass insulating blocks. Technical textiles made of E-glass fibers have been mainly used since 1930, for their thermal resistance at high temperatures, in the field of fire protection (fire curtains and smoke barriers), thermal and acoustic insulation in industry, naval, automotive, aeronautical, metallurgy and furnaces.

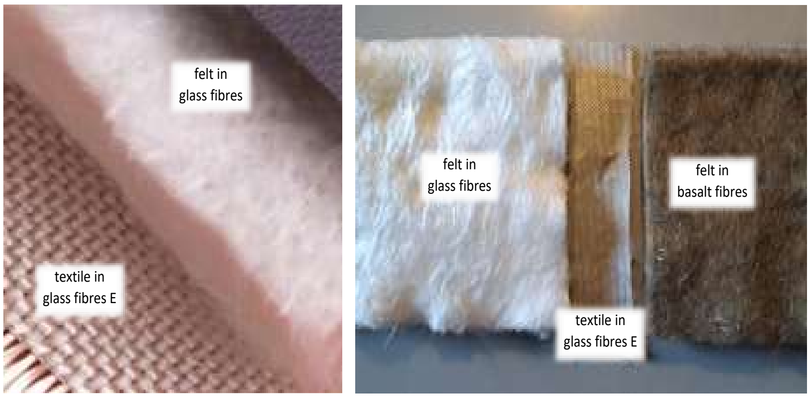


Figure 14: Type E glass fiber textile and felt (photo final-materials.com) and FOAMGLAS® cellular glass panel

KLEVERS GmbH in Germany produces E-glass fiber textiles (KlevoGlass) in grammages between 160 and 1050 g/m^2, with thicknesses of 0.18 to 1.3 mm and widths of up to 310 cm. These can be reinforced with stainless steel wires (V4A). Their tensile strength can reach 900 N/cm, i.e., 9 tonnes per meter of textile width (according to European standard: EN ISO 13934-1), which (according to Appendix, Extended report, § 8.4.1, eq. 8.41) is 1,5 times the maximum linear load of 6 t/m to which the ULISSE enclosure is subjected.

Cellular glass (based on approximately 60% recycled flat glass, windshields, windows) is completely water and vapor tight. It has very good compressive strength, from 500 to 1600 kPa, depending on the density (100 to 165 kg/m^3). FOAMGLAS notably supplies standard plates (50 x 600 x 450 mm, source FOAMGLAS, Pittsburgh Corning Schweiz AG).

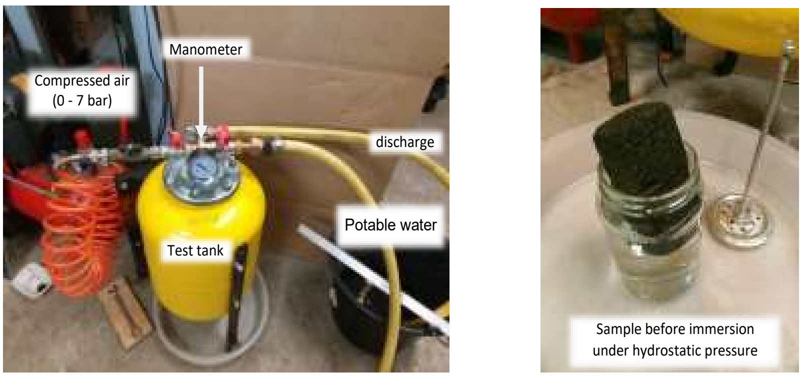


Figure 15: General layout of the hydrostatic test of FOAMGLAS cellular glass

Illustrated in Figure 15 above, conclusive hydrostatic tests were carried out on cellular glass samples from a standard "entry-level" FOAMGLAS plate, with a density of 100 kg/m^3 and 165 kg/m^3. They did not undergo any alteration at 7 bars (maximum available by the test device).

3.1.8 Analysis of the heat transfer by the envelope of the ULISSE Reservoir

The efficiency of the long-term (seasonal) storage of hot water in the sub-lake Reservoir increases with the ratio between its Volume and the Surface of its envelope as well as with the Thermal Resistance (Rt) of the latter. Illustrated in Figure 16 below, the Rt or conversely the thermal conductance (Ct) of the envelope is essentially determined by that of the cellular glass insulating blocks (Ctp), that of the spacer joints (Ctji) and that of the junctions of the strips of the envelope (Ctjb).

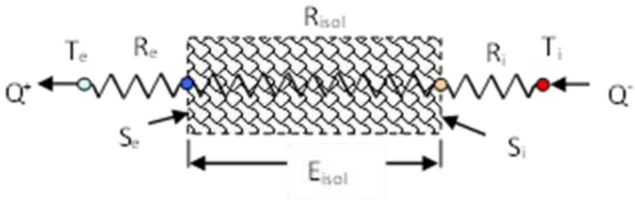


Figure 16: Representation of the simplified thermal model of the Reservoir envelope

Conductance of insulating blocks (cellular glass)

The thermal conductance of an insulating block (Ctp) is determined by its thermal conductivity (λp: 0.05 W/m.K), surface area (S) and thickness (ε: 0.05 m). FOAMGLASS offers two standard sizes of cellular glass slabs (S_{-1}: 0.6 x 0.45 m = 0.27 m^2 and S_{-2}: 1.2 x 0.6 m = 0.72 m^2):

$$Ctp\text{-}1 = S_{-1}\,(\lambda p / \varepsilon) = 0.27\,(0.05/0.05) = 0.27 \quad [W/K] \qquad (2)$$
$$Ctp\text{-}2 = S_{-2}\,(\lambda p / \varepsilon) = 0.72\,(0.05/0.05) = 0.72 \quad [W/K] \qquad (3)$$

The surface thermal conductivity of the two sizes of the blocks (S_{-1}, S_{-2}) remains equal to 1 W/m^2K.

Conductance of spacer joints

The spacer joints are composed of a mattress of E-fiberglass or basalt felts, with an uncompressed density (m) of 100 to 170 kg/m^3 for fiberglass and 120 to 137 kg/m^3 for basalt fiber. Filled with interstitial dry air, these materials have low thermal conductivity (λf: 0.03 to 0.038 W/m.K) and are used in particular as thermal insulation in high temperature applications (≈ 700˚C, source: Final Advanced Materials), performance which is obviously not required for ULISSE.

However, when immersed in water, the interstitial space between the fibres is filled with water, whose CONVECTION-FREE thermal conductivity (λ_e: 0.58 W/m.K at 10˚C) is almost 30 times greater than that of dry air ($\lambda_{a:}$ 0.02 W/m.K). The precise function of the fibre structure or matrix is to reduce the free convection of the "insulating or heat transfer fluid" (air, gas or water in our case) inside, and to do so with a minimum of structural mass (which is more conductive).

According to Figure 17 below, the unit length (Luj) of the joint corresponds to half the circumference of a block. The unit length then depends on the standard format of FOAMGLASS block (S_{-1}, S_{-2}):

for S_{-1} (0.6 x 0.45 m = 0.27 m^2) $\quad L_{uj\text{-}1}$ = 0.6 + 0.45 m = 1.05 [m] (4)
for S_{-2} (1.2 x 0.6 m = 0.72 m^2) $\quad L_{uj\text{-}2}$ = 1.2 + 0.6 m = 1.8 [m] (5)

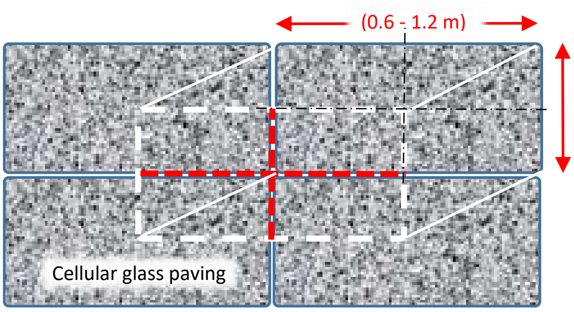


Figure 17: Unit length of interlayer joint (Luj) equal to half the circumference of a cellular glass block

It is simply considered that the seal consists of 2 distinct thermal resistors; one solid in fiber and the other liquid in water. Illustrated in Figure 18 below, similar to an electrical circuit of intertwined resistors, distorted (discontinuous) and the resulting heat flows disturbed, reducing the actual thermal conductance of the joint (Ctjr).

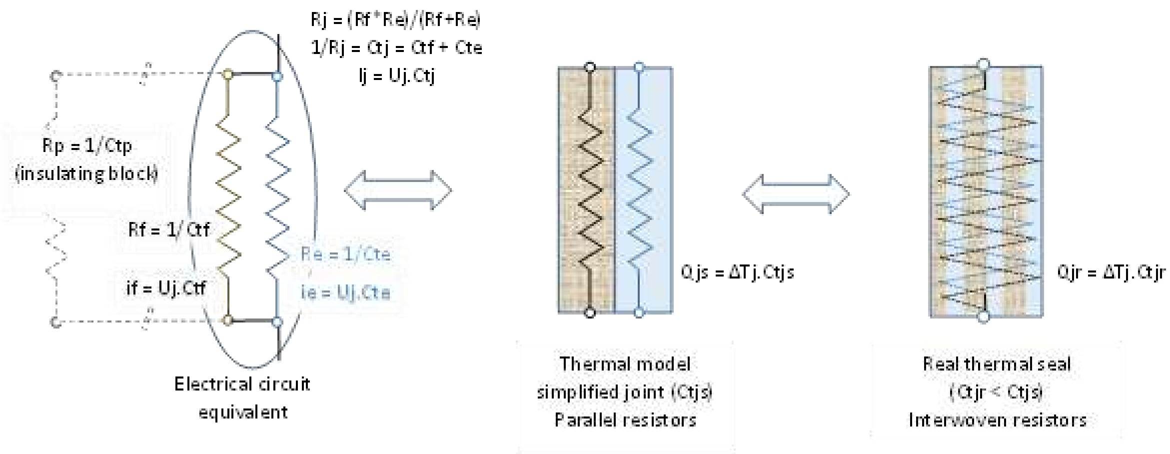


Fig. 18: Equivalent electrical circuit of the simplified and real thermal model of the seal

The thermal conductance of the envelope, with the thermal bridge of the spacer joints (Ctp+j) with respect to the paving increases from 21 to 44%, depending on the size of the paving and the width of the joints in glass “(v)erre” or in (b)asalt.

Linear thermal conductance of the junction zone of the envelope bands (Ctjon)

The junction of the strips of the envelope constitutes a "linear" thermal bridge (per meter of length). Illustrated in Figure 12 above, the connecting jaws (stainless-steel) are covered with a thermal insulation jacket which consists of several layers of fiberglass or basalt felt. To determine the linear thermal resistance (Rt_L) or conversely the linear thermal conductance (Ct_L), the junction area is divided into its constituent elements, characterized by the width (L), the thickness (ε) and the conductivity heat (λ) specific to the material of each element, similar to a circuit of electrical resistors represented in Figure 19 below.

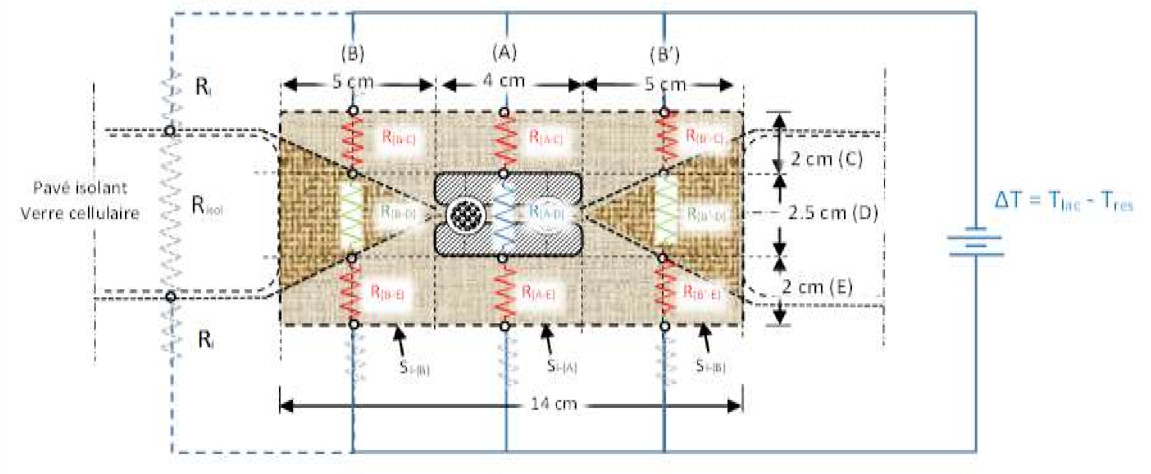


Figure 19: Cross section of the junction zone of the envelope strips and its equivalent thermal circuit

The equivalent linear thermal resistance (Rt_L) is as follows:

$$Rt_L: R_B \,//\, R_A \,//\, R_{B'} \;\Rightarrow\; Rt_L = 1 / [C_B + C_A + C_{B'}] = 1 / [\,(1/R_B) + (1/R_A) + (1/R_{B'})\,]$$
$$= 1 / [\,(1 / (R_{B-C} + R_{B-D} + R_{B-E})) + (1 / (R_{A-C} + R_{A-D} + R_{A-E})) + (1 / (R_{B'-C} + R_{B'-D} + R_{B'-E}))\,] \qquad (6)$$

It is observed that the thermal conductance of the junctions (Ctjon) represents approximately 10% of the total thermal conductance of the envelope. With the Cts of the paving stones, of the spacer joints (thickness. 1 cm) and of the joint of the strip, the thermal conductivity of the envelope (λenv) is deduced, for example, for the large format of isolation blocks and fiberglass (-2v):

$$\lambda env\text{-}2v = Ctbe\text{-}2v * € / Sbe = 2{,}498 * 0.05 / 1{,}884 = 0.066 \quad [W/mK] \qquad (7)$$

3.2 Experimental Mock-up

The Mock-up reproduces the various operating phases of the ULISSE Reservoir in order to analyse and establish the efficiency of its sub-lacustrine seasonal energy-heat storage system. The Mock-up represents a "linear slice" (1/5) of the shell of the Reservoir, at a reduced scale of 1/175. At the two longitudinal ends, the shell is "strongly insulated" (relatively a-thermal walls) by a 4 cm thick extruded polystyrene sheet ($\lambda \approx 0.035$ W/m.k, => $U \approx 0.9$ W/m^2.K).

Illustrated in Figure 20 below, the hyperbolic envelope of the Mock-up is reduced to a thin (2 mm) and transparent polycarbonate sheet ($\lambda \approx 0.21$ W/m.k, => $U = 105$ W/m^2.K). The transverse curvature being close to the hyperbola with an average radius of 30 cm (28.5 at the base and 31.3 at the top), which gives a cross section (x, y axes) of 1,238 cm^2 (≈ 97% of the equivalent semi-circular arc). Between the end plates, the length of the envelope being 62 cm (z-axis), the corresponding volume of the Mock-up is approximately 77 litres.

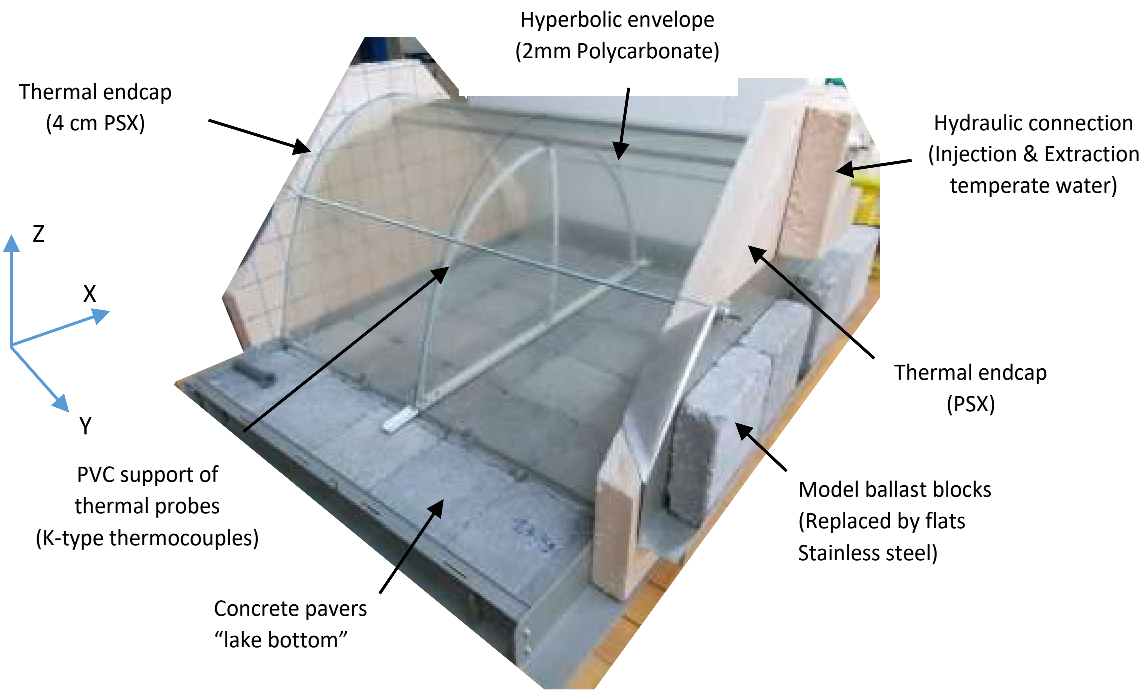


Figure 20: ULISSE Mock-up

Illustrated in Figure 21 below, the Mock-up is placed in a 1,000-litre plastic IBC tank with iron basket reinforcement, fixed on a plastic pallet (120 x 100 cm). The ratio between the volume of water in the IBC tank and the Mock-up is a maximum of 12.

Figures. 21 & 22: ULISSE Mock-up in the IBC test tank connected to the hydrothermal supply unite (HSU)

Temperature measurement thermocouples

At each end of the summit ramp (Figure 23 below), top injection (Summer Loading) and water extraction (Winter Discharging) of the Mock-up, is fixed a temperature probe (thermocouple type K, TC9/10). The temperature and water flow measurements at the level of the ramp make it possible to quantify the heat introduced (Qm-e) and extracted (Qm-h) from the Mock-up over a complete cycle (pseudo-annual).

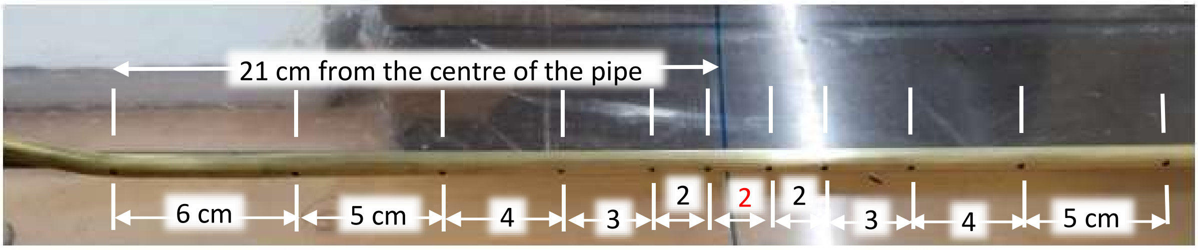


Figure 23: Summit ramp for summer injection (Qm-e) and winter extraction (Qm-h)

The measurements are mainly thermal in order to know the temperature and also to indirectly deduce the convective movements of water in the Mock-up as well as those in the IBC tank (representing the lake).

Fig. 24: thermocouples type K *Fig. 25: Transversal thermocouple support*

Temperature probes (type K thermocouples, Figure 24) are also placed in the Mock-up on a transverse PVC support which can be moved longitudinally (Figure 25).

Illustrated in Figure 26 below, the thermocouples are connected to a Micrologger measurement and data acquisition interface (CR3000 from Campbell Scientific. The latter also records the rate/volume of hot water loading and unloading from the Mock-up, via the pulse flow meter (FM) located on the hydrothermal supply unit (HSU) illustrated in Figure 22 above.

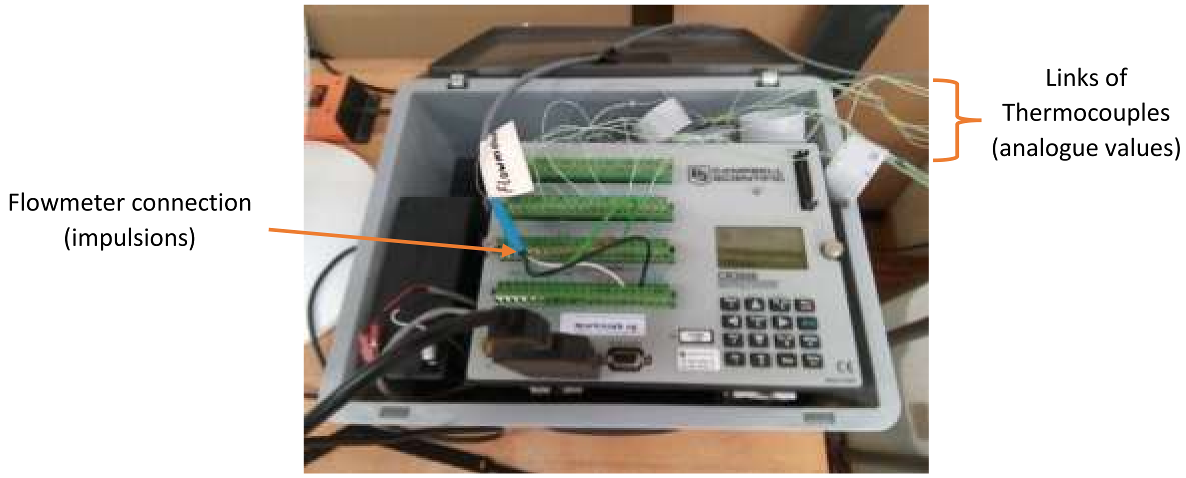


Figure 26: Campbell Scientific Micrologger CR3000 data acquisition box

Example of a complete cycle on the Mock-up (test on 20.12.2022, Appendix 1.8, Extended report)

Illustrated in Figure 27 below, this test includes a complete cycle on the Mock-up, with Summer Loading (**SL)**, Autumn Stagnation (**AS)** and the Winter Discharging phase (**WD**). To reduce or eliminate mixing during the injection of hot water at the top of the Mock-up, a distribution grid with a layer of fibreglass felt was placed under the injection bar (Figure 21 above). **Continued in Appendix 1.8.**

The test with the grid and the distribution felt for filling did not influence the unloading results!

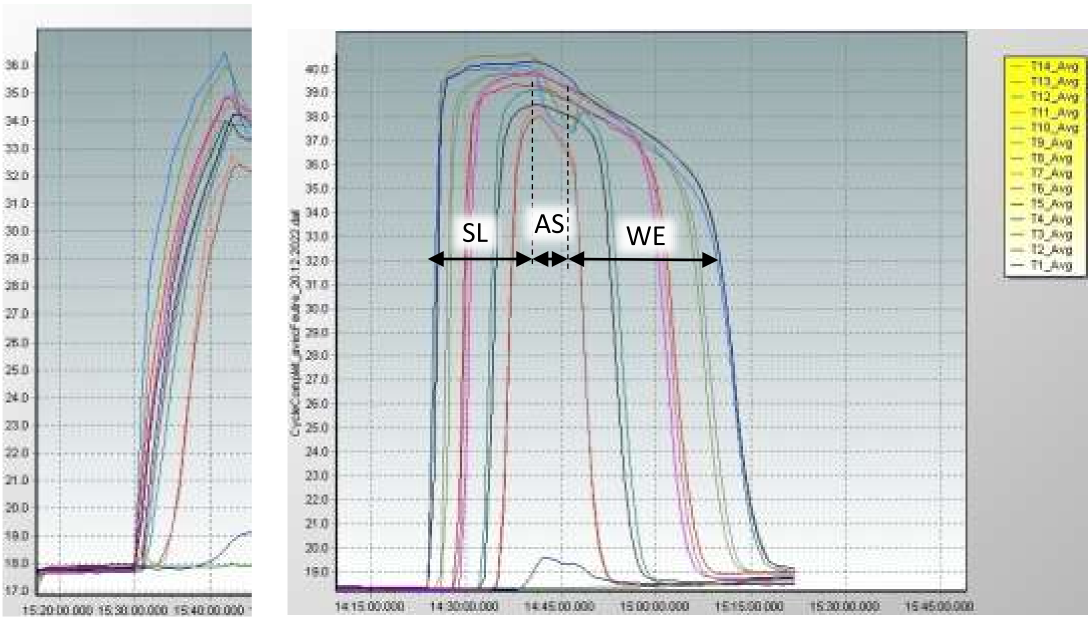


Figure 27: Comparison of stratification during the loading phase, without (fig. left) and with (fig. right) a grid + felt distributor of the water injection flow (same flow) via the top ramp of the Mock-up (tests 19 and 20.12.2022)

3.3 Time Scale Factor (TSF) of Real full-size Ulisse Reservoir vs Mock-up

3.3.1 Dimensional analysis

A dimensional analysis is essential to establish a relationship between the characteristic time of the real ULISSE Reservoir and that of the Mock-up. Illustrated in Figure 28 below, the Mock-up represents a "linear slice" of about 1/5 of the real Reservoir (figure 26 below). The ratio of the volume of the slice of the Reservoir to that of the Mock-up (4.10^5 m^3 / 7.7 10^{-3} m^3) is 4.7 10^6.

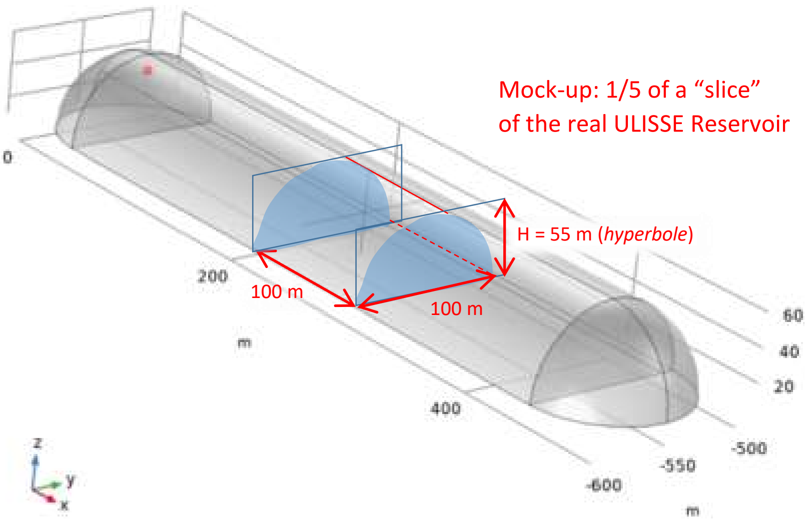


Figure 28: Approximate perspective representation with dimensions (m) of the real Reservoir (2 10^6 m^3) and the "slice" (1/5 = 400,000 m^3) corresponding to the Mock-up *(0.077 m^3)*
(Base figure: Roland Rozznyo, HEPIA, COMSOL Multiphysics software, ULISSE numerical simulation)

From certain points of view, two isomorphic objects can be considered to be identical, or at least indistinguishable, which makes it possible to transpose results and properties demonstrated for one to the other. In many cases, the interesting properties of one object will be shared by all the isomorphic objects in the category (source: Wikipedia/Isomorphism).

If the characteristic geometric ratios of the full-scale Reservoir envelope are the same as those of the Mock-up: [hyperbola of radius (R) at the base, with the length of curvature (Loh) in an identical ratio of (π = Loh/Rc) and the said base (2Rc) equals the longitudinal length (L) of the envelope], they can be considered as isomorphic and assigned a *form factor* (FF) equal to -1-.

However, in addition to their shape and size ratios (Rr/m, Lr/m), the respective material and thickness of their envelope are not the same (5 cm of cellular glass for the real tank vs 2 mm of polycarbonate for the Mock-up).

In addition, the thermal conductivity of the envelopes (λenv: λr, λm) also differs from the fact that, contrary to the Mock-up, the envelope of the real Reservoir comprises, in addition to the cellular glass blocks, the spacer joints (Ctjin) and the junctions' strips of the envelope (Ctjon). These increase the total thermal conductivity of the envelope of the real ULISSE Reservoir compared to that of the blocks alone (λenv: 0.05 => 0.066 W/m.K, see § 3.1.8, eq. 7).

In order to be able to correctly interpret, between them, the results of the measurements obtained experimentally (Physical Mock-up) with those obtained by calculations (Excel, COMSOL numerical simulation), their appropriate Time Scale Factor (TSF) is determined. This will correlate the different dimensional ratios and the characteristics of the materials that make up the envelope of the two objects (real life-size ULISSE Reservoir and reduced-scale Mock-up).

The dimensional analysis, not explained further here, shows a relationship between the characteristic time specific to the real Reservoir with that of the Mock-up and which is qualified here as the Time Scale Factor of the Reservoir/Mock-up (TSF). With a Reservoir/ Mock-up form factor equal to 1, we obtain the following TSF:

$$TSF = t_r / t_m = (FF) . (Rr / Rm) . (Epr / Epm) . (\lambda m / \lambda r) \quad [-] \quad (8)$$

$$TSF = (1) . (50 / 0,29) . (0,05 / 0,002) . (0,21/ 0,066) = \mathbf{13'715} \quad [-] \quad (9)$$

with:

t_r	the characteristic time of the real Reservoir	
t_m	the characteristic time of the Model	
FF	Real Reservoir / Mock-up form factor	(1)
Rr	the characteristic transverse radius of the real reservoir	(50 m)
Rm	the Characteristic Transversal Radius of the Mock-up	(0,29 m)
Épr	the thickness of the Reservoir envelope (cellular glass insulation)	(0.05 m)
Epm	the thickness of the Mock-up envelope (polycarbonate)	(0,002 m)
λr	Thermal conductivity of the Reservoir envelope	(0,066 W/m.K)
λm	Thermal conductivity of the Mock-up envelope	(0,21 W/m.k)

Clearly, the TSF = 13,715 means that **1 minute elapsed for the Mock-up corresponds to 13,715 minutes, or almost 229 hours or almost 10 days** of **elapsed time (t_r) for the real Reservoir!**

One complete cycle of a real year (t_r = 8,760 h) corresponds to 38.3 minutes of Mock-up time (t_m), i.e., **1 real month of Reservoir corresponds to 3.2 minutes of Mock-up time**.

The ratio (13,715) between the duration of the different operating phases (Fig. 10 above, § 3.1.4) over a real year (t_r) would then correspond for the Mock-up (t_m) to:

		Reservoir (t_r)		**Mock-up (t_m)**	
1. Summer Loading	(SL)	2 months	<=>	6.4	minutes
2. Autumn stagnation	(AS)	2 months	<=>	6.4	minutes
3. Winter Discharging	(WD)	6 months	<=>	19.1	minutes
4. Spring Stagnation	(SP)	2 months	<=>	6.4	minutes
Annual operating cycle		12 months (t_r)	<=>	38.3	minutes (t_m)

According to this first approach, with an TSF = 13,715, between the real Reservoir and its reduced-size Mock-up, the temporal evolution of their internal temperatures and therefore also of their energy balances can be correlated.

3.3.2 Energy balance of the real ULISSE Reservoir and the Mock-up

To establish the efficiency of the seasonal energy-heat storage of the ULISSE Reservoir, the heat losses of all the annual operating phases of the full-scale Reservoir and of its reduced-scale Mock-up were determined and accounted for. **In this energy balance, a clear distinction was made between *heat loss and summer loading***. In this way, we have defined, globally, the *Gross Heat Losses* - (GHT, including that of Autumn Stagnation, Winter Discharging, - and - Summer Loading,) and the *Net Heat Losses* - (NHL, without SL).

Its justification lies in the fact that **the *Summer Heat Loss* (*SHL)* of the ULISSE Reservoir is not a major issue,** as the electrical energy used to power the pumps would essentially come from photovoltaic (PV) sources. Furthermore, with the massive development of PV, the summer loading of the ULISSE Reservoirs would reduce the potential and paradoxical recourse to "peak-shaving" (capping excess summer electricity production by shutting down PV installations).

Incidentally, the Summer Heat Loss of the ULISSE Reservoir is the sum of the heat loss from its shell and the excess water injected above its volumetric capacity. The latter results from the partial compensation of the shell loss and the modification of the internal thermocline of the Reservoir (by thermal diffusion and multiple mixing). The establishment of the energy balance or storage efficiency of the ULISSE Reservoir and the Mock-up therefore starts from the thermal capacity or the **Net or Nominal Summer Load (NSL)**.

Heat losses are calculated using 3 different approaches:

- 1. by calculation using a **theoretical model** of the Mock-up and the full-scale Reservoir, taking into account the *"active" surface area* (Sa) and the *thermal conductivity* (Cot) of the insulating envelope as well as the difference (∆Tr-l) between the average temperature of the Reservoir (Tr) and that of the surrounding lake (Tl). Specifically, for the dynamic phases, by integrating the evolution of the heat loss as a function of the filling of the Reservoir or the level of the thermocline ("active" volume of hot water).

- 2. calculations based on actual physical data (temperatures, flow rates) acquired from **experience on the Mock-up,** reproducing the main part of the annual operating cycle, which includes the "dynamic" phases (*summer loading, winter discharging*) and the "static" *autumn stagnation* phase.

- 3. **numerical simulation** (COMSOL Multiphysics) of the Mock-up and the real Reservoir.

Before carrying out the experiments on the model, ***the Time Scale Factor (TSF)*** **between the full-scale Reservoir and the Mock-up** was determined (section 10). In order to check the consistency between the Mock-up, the real Reservoir (theoretical model) and the numerical simulation, we compared the ***Characteristic Time Constant*** *(τ_r) of their* respective *passive cooling.* This makes it possible to validate the consistency (convergence) between the results of the three approaches.

Theoretical model

According to Figure 29 below, the theoretical model considers that the active surface (Sa) and the active volume (Va) of the Reservoir or the Mock-up evolve at each period of time and that the heat loss is exclusively located in the part "active" (hot) through the active surface of the Reservoir shell.

The theoretical model also makes the simplified assumption of a homogeneous average temperature in the active volume (by convection and advection). The thermal stratification in the Reservoir is then reduced to a flat-fronted thermocline, which separates the “active” (warm) upper part from the “passive” lower part (cold or of the same temperature as the surrounding lake).

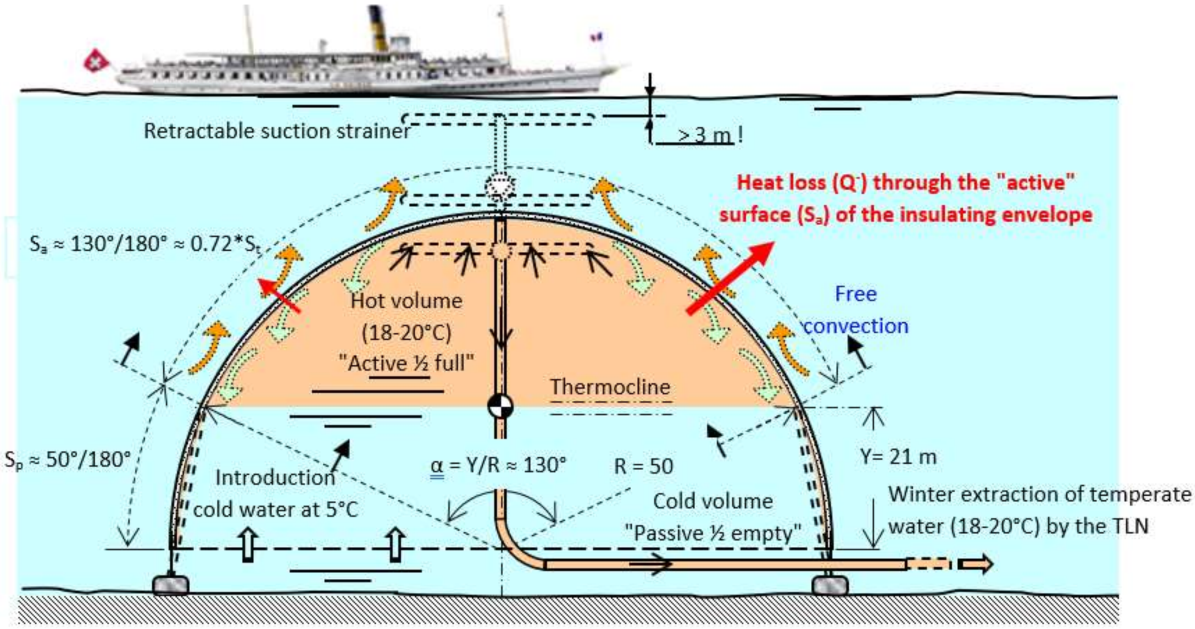


Figure 29: Theoretical model of heat loss (Q-) from the sub-lacustrine Reservoir, shown as an average value at half volume, during the Winter Unloading phase for heating buildings via the distribution network

3.3.3 Theoretical calculations for the real ULISSE Reservoir

The truncated Table 30 below corresponds to the theoretical calculations of heat loss from the hyperbolic envelope of the real ULISSE Reservoir; this is for the "static" Autumn Stagnation (AS) phase lasting 2 months (line 23, grey background), followed by the "dynamic" Winter Discharging (WD) phase lasting 6 months.

More precisely, the WD phase is calculated here using two approaches: one based on "*mean values at mid-active volume*" (line 26, blue background) and the other by "*integration"* of jumps in the level of the flat-front *thermocline* or the interface between the hot and cold-water volumes (lines 31-81, green background).

We observe in Table 30:

- Line 23 (grey background), the autumn stagnation phase (1,460 hours or 2 months, G23), has a Stagnation Thermal Loss (STL) of 2 GWh, i.e., 5.71% of the Net or Nominal Summer Load (NSL: 35 GWh or 126 TJ).
- Line 26 (blue background), the Winter Unloading phase (4,380 h or 6 months, G26), calculated by "*average values at half active volume*", is subject to a Discharging Thermal Loss (DTL) of 3.81 GWh, i.e., 10.89% of the NEC.
- Finally, between column lines 31K-L and 81K-L, the Winter Unloading phase, which is identical but calculated by "*integrating the jumps in the thermocline level*", incurs a Discharging Thermal Loss (DTL) of 3.62 GWh, i.e., 10.34% of the Nominal Summer Load (NSL).

Initial 'theoretical' conclusions:

- The two methods for the theoretical calculation of the Reservoir Winter Discharging phase are logically identical.
- According to theoretical calculations, **the *Net Thermal Loss* (NTL)**, being the sum of the AS and WD phases, **represents almost 16% of the NSL of the ULISSE Reservoir.**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Calculs théoriques de l'enveloppe hyperbolique du Réservoir ULISSE : 1) en Phase de Stagnation Automnale (plein volume "actif"),**													
2	**2) en phase de Déchargement Hivernal (par valeurs moyennes à mi-volume "actif" et par intégration des niveaux de la thermocline)**													
3	La stratification thermique du réservoir est constituée d'une "**Thermocline à front plat**", séparant le volume "actif" (chaud) du volume "passif" (froid =Tmoylac)													
4	La déperdition thermique est calculée en valeur moyenne sur le volume "actif" et sur la durée respective des 2 phases (2 et 6 mois)													
5	Rayon de courbure hyperbolique à la base :				Rhb	**50**	m				Volume total calotte hyperboloïde :	Vcal	253 800	m3
6	Longueur hyperbolique transversale :				Lht	157,08	m				Volume total réservoir :	Vres	**2 005 020**	m3
7	Longueur hyperbolique longitudinale :				Lhl	460	m				Epaisseur Isolant (verre cellulaire) :	Eiso	0,05	m
8	Longueur totale réservoir :				Ltr	560	m				Conductivité totale enveloppe :	λenv	0,066	W/mK
9	Surface calotte hyperboloïde d'extrémités :				Scal	15 708	m2				Conductivité enveloppe surfacique :	λenvs	1,32	W/m2K
10	Surface totale enveloppe :				Senv	87 965	m2				Chaleur volumique eau douce :	Cve	1,163	kWh/m3 K
11	Section hyperbolique transversale :				Sht	3 807	m2				Ecart densité eau stock-lac (ΔT = 15 °K) :	Ds-l	-1,76	kg/m3
12	Température Hivernal du Lac = température minimale réservoir :						Thlac	5	°C			Débit de Déchargement Hivernal:	457,77	m3/h
13	Température de Contact du Lac avec le réservoir :						Tcontlac	7,5	°C			(constant)	0,13	m3/s
14	Température nominale du stock à la fin du Chargement Estival :						Tnomrés.	**20**	°C					
15	Ecart maximum Température réservoir-lac :						ΔTmax.r-l	**15**	°K			**Charge therm. nominale (Qtn) :**	**34,98**	**GWh**
16														
17	Niveau	Longueur	Section	Surface	Volume	Conductance	Temps	Gradiant	Gradiant	Charge	Perte	Perte	Chute	Température
18	hauteur	hyperbole	transvers	enveloppe	enveloppe	enveloppe	différentiel	thermique début	thermique final	thermique	thermique	thermique	Température	final
19	Thermoc line	"active" Loha 2*√(2ah+h	"active"	"active"	"active"	"active"		Réservoir - Lac	Réservoir - Lac	résiduelle	enveloppe	enveloppe	Réservoir	Réservoir
20	Ntc	2)	Seta	Sura	Vola	Conda	td	ΔTdr-l	ΔTfr-l	Qtr	Pte	Pte	ΔTr	Tfr
21	[m]	[m]	[m2]	[m2]	[m3]	[KW/K]	[h]	[°K]	[°K]	[GWh]	[GWh]	[%]	[°C]	[°C]
22	**Phase (statique) de Stagnation Automnale (plein volume "actif")**													
23	0,00	157,09	3 807	87 965	2 005 020	116,11	1 460	12,5	11,79	32,98	**2,00**	**5,71**	0,714	19,28596
24														
25	**Phase (Dynamique) de Déchargement Hivernal (calculs par valeurs moyennes à mi-volume "actif")**													
26	**20,66**	112,00	1 977	62 715	**1 041 383**	82,78	4 380	11,79	10,50	31,17	**3,81**	**10,89**	1,283	18,00274
27														
28	**Phase (Dynamique) de Déchargement Hivernal (calculs par Intégration des niveaux de la thermocline)**													
29	Ntc	Loh	Seca	Sura	Vola	Conda	td	ΔTdr-l	ΔTmr-l	Qtr	Pte	Pte	ΔTr	Tmr
30	[m]	[m]	[m2]	[m2]	[m3]	[KW/K]	[h]	[°K]	[°K]	[GWh]	[GWh]	[%]	[K]	[°C]
31	2,65	151,42	3 544	84 791	1 866 745	111,92	302	11,79	11,65	32,59	**0,39**	1,19	0,141	**19,14526**
32	5,21	145,93	3 306	81 717	1 740 909	107,87	275	11,65	11,53	32,24	**0,34**	1,05	0,114	**19,02308**
33	7,67	140,61	3 080	78 739	1 622 170	103,94	259	11,52	11,41	31,94	**0,31**	0,95	0,110	**18,91312**
34	10,04	135,46	2 867	75 855	1 510 200	100,13	245	11,41	11,31	31,66	**0,28**	0,87	0,099	**18,81409**
35	12,33	130,47	2 667	73 061	1 404 687	96,44	230	11,31	11,22	31,41	**0,25**	0,79	0,089	**18,72492**
36	14,53	125,64	2 478	70 353	1 305 329	92,87	217	11,22	11,14	31,18	**0,22**	0,72	0,080	**18,64464**
37	16,65	120,95	2 301	67 728	1 211 841	89,40	204	11,14	11,07	30,98	**0,20**	0,65	0,072	**18,57239**
38	18,69	116,41	2 134	65 183	1 123 947	86,04	192	11,07	11,01	30,80	**0,18**	0,59	0,065	**18,50741**
39	**20,66**	112,00	1 977	62 715	**1 041 383**	82,78	180	11,01	10,95	30,64	**0,16**	0,53	0,058	**18,44898**
40	22,54	107,72	1 830	60 322	963 896	79,62	169	10,95	10,90	30,49	**0,15**	0,48	0,052	**18,39650**
79	54,66	2,00	149	1 120	78 529	1,48	0	10,49	10,49	29,36	**0,00**	0,00	0,000	**17,99316**
80	54,68	0,00	149	0	78 538	0,00	**4 208**	10,49	10,49	29,36	**0,00**	0,00	0,000	**17,99316**
81										**29,36**	**3,62**	**10,34**	**1,285**	
82	[m]	[m]	[m2]	[m2]	[m3]	[KW/K]	[h]	[°K]	[°K]	[GWh]	[GWh]	[%]	[°C]	[°C]
83	Ntc	Loha	Seta	Sura	Vola	Conda	td	ΔTdr-l	ΔTfr-l	Qtr	Pte	Pte	ΔTr	Tfr

Table.30: - truncated theoretical calculations of the heat losses of the hyperbolic envelope of the ULISSE Reservoir, for the Autumn Stagnation and Winter Discharging phase

3.3.4 Theoretical calculations for the Mock-up

The Excel Table 31 below corresponds to the theoretical heat loss calculations for the hyperbolic envelope of the model; this is for the "static" Autumn Stagnation (AS) phase lasting **6 minutes** (2 real months), followed by the "dynamic" Winter Discharging (WD) phase lasting **19 minutes** (6 real months).

More specifically, the WD phase is only calculated here using the "*mean values at mid-active volume*" approach. The other method using "*integration of jumps in the thermocline level*" is not used, as the results of the two theoretical calculation methods are identical (previous conclusions for the Reservoir).

We also observe in Table 31:

- Line 23K-L (grey background), the Autumn Stagnation phase (0.1065 hours: 23G) incurs a Stagnation Thermal Loss (STL) of 0.07 GWh, i.e., 5.49% of the Net Thermal Load (NTL: 1.34 kWh or 4.8 MJ).

- Line 26K-L (blue background), the Winter Discharging phase (0.3194 hours: 26G), calculated by "*average values at half active volume*", incurs a Discharging Heat Loss (DHL) of 0.14 kWh, i.e., 10.46% of the Net Heat Load (NHL).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	**Calculs théoriques de l'enveloppede hyperbolique de la Maquette ULISSE :**													
2	**1) en Phase de Stagnation Automnale (plein volume "actif"), 2) en phase de Déchargement Hivernal (par valeurs moyennes à mi-volume "actif")**													
3	La stratification thermique de la maquette est constituée d'une "**Thermocline à front plat**", séparant le volume "actif" (chaud) du volume "passif" (froid =Tmoylac)													
4	La déperdition thermique est calculée en valeur moyenne sur le volume "actif" et sur la durée respective des 2 phases (6 et 19 minutes)													
5	Rayon de courbure hyperbolique à la base :				Rhb	**0,285**	m			Volume total calotte hyperboloïde :		Vcal	0	m3
6	Longueur hyperbolique transversale :				Lht	0,9	m			Volume Maquette :		Vres	0,077	m3
7	Longueur hyperbolique longitudinale :				Lhl	0,62	m			Epaisseur Isolant (verre cellulaire) :		Eiso	0,002	m
8	Longueur totale réservoir :				Ltr	0,62	m			Conductivité totale enveloppe :		λenv	0,21	W/mK
9	Surface calotte hyperboloïde d'extremités :				Scal	0	m2			Conductivité enveloppe surfacique :		λenvs	105	W/m2K
10	Surface totale enveloppe :				Senv	0,56	m2			Chaleur volumique eau douce :		Cve	1,163	kWh/m3 K
11	Section hyperbolique transversale :				Sht	0,12	m2	Echelle de temps Réservoir/Maquette : (Tr/Tm) =					13 715	-
12	Température Hivernale Maquette = température minimale Maquette :						Thlac	5	°C	Débit de Déchargement Hivernal:			0,241	m3/h
13	Température de Contact de la Cuve avec la Maquette :						Tcontlac	7,5	°C			(constant)	4,018	Lit/min
14		Température nominale du stock à la fin du Chargement Estival :					Tnomrés.	**20**	°C					
15	Ecart maximum Température entre maquette et cuve :						ΔTmax.r-l	15	°K	**Charge thermique initiale (Qti) :**			**1,34**	**kWh**
16														
17	Niveau	Longueur	Section	Surface	Volume	Conductance	Temps	Gradiant	Gradiant	Charge	Perte	Perte	Chute	Température
18	hauteur	hyperbole	transversale	enveloppe	enveloppe	enveloppe	différentiel	thermique	thermique	thermique	thermique	thermique	Température	finale
19	Thermocline	"active" Loha 2*√(2ah+h	"active"	"active"	"active"	"active"		début Maquette-Cuve	final Maquette-Cuve	résiduelle	enveloppe	enveloppe	Maquette	Maquette
20	Ntc	2)	Seta	Sura	Vola	Conda	td	ΔTdr-l	ΔTfr-l	Qtr	Pte	Pte	ΔT	Tfr
21	[m]	[m]	[m2]	[m2]	[m3]	[KW/K]	[h]	[°K]	[°K]	[kWh]	[kWh]	[%]	[K]	[°C]
22	**Phase (statique) de Stagnation Automnale (plein volume "actif")**						(6 min)							
23	0,00	0,90	0,12	0,56	0,08	0,06	**0,1065**	12,5	11,81	1,27	**0,07**	**5,49**	0,686	19,31430
24														
25	**Phase (Dynamique) du Déchargement Hivernal**						(19 min)	(calculs en valeurs moyennes à mi-volume "actif")						
26	**11,33**	0,64	0,09	0,40	0,04	0,04	**0,3194**	11,81	10,58	1,20	**0,14**	**10,46**	1,236	18,07829

Table 31: Theoretical calculations of heat losses from the hyperbolic envelope of the Mock-up, for the Autumn Stagnation and Winter Discharging phases (average values)

3.3.5 Theoretical and experimental energy balance of the Reservoir and the Mock-up

The upper frame (A1 to N23) of Table 32 below shows (in columns C to N), the times, flow rates and temperatures of the phases, SL (green background), AS (grey background) and WD (blue background); this (according to lines 6 to 18) for the various Tests on the Mock-up and Theoretical Calculations with the Reservoir and the Mock-up.

The lower frame (A20 to N38) shows the Gross and Net Loads and Heat Losses, and conversely the Net Storage Efficiency, NSE (yellow background), for the Reservoir and the Mock-up.

The Winter Heat Loss (WHL, blue background) is logically proportional to its duration. This is particularly true for the Test on 24.11.2022, where the WHL is 18.44% (K26) of the NHL (D26), given a duration of 41 minutes (F6), i.e., more than twice the time normally required (19 min) to comply with the TSF.

The WHL of all the other tests, including the theoretical calculations on the Reservoir and the Mock-up, are between 9.65% (K27) and 12.71% (K29). The Stagnation Heat Loss (SHL) is 5 to 6%.

Finally, the Net Storage Efficiency (NSE), for the Reservoir and the Mock-up, is between 74,80% (N30) and 89,06% (N37), with an average of nearly 83% (N26-N38).

This initial energy balance, the results of which are consistent, shows that the *Time Scale Factor* (TSF), the *theoretical model of* the Reservoir and the Mock-up, and their *thermal time constants* ($\tau_{r/m}$), validated by experiment on the Mock-up, are well-founded.

However, this preliminary energy balance is based on the assumption that the Reservoir behaves exactly like the Mock-up which has yet to be demonstrated with full numerical simulation (CONSOL).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1			Temps	Temps	Temps	Temps	Débit	Débit	Températ.	Températ.	Maquette	Gain	Chute	Chute
2			Charge	Stagnat.	Décharge	Décharge	Charge	Décharge	Lac	Lac	Début	Températ.	empératur	empératur
3					(100% Vol)	(total Q)	(moyenne)	(moyenne)	(Fond)	(moyenne)	Décharge	Chargemen	Stagnation	Stagnation
4	Type	Date	tc	ts	tdv	tdq	dc	dd	TLF	TLM	TDD (TFS)	ΔTC	ΔTS	ΔTS/ΔTC
5	Essai/Calcul	[j:m:a]	[min]	[min]	[min]	[min]	[Lit/min]	[Lit/min]	[°C]	[°C]	[°C]	[K]	[K]	[%]
6	Essai Maq.	24.11.2022	14	-	32	41	2,01	2,26	19,7	20,01	35,48	16,17	-	-
7	Essai Maq.	19.12.2022	14	6	19	27	6,07	3,91	17,9	17,98	33,35	16,06	0,83	5,17
8	Essai Maq.	20.12.2022	17	6	25	33	6,21	2,94	18,3	18,69	38,37	21,15	1,29	6,10
9	Essai Maq.	21.12.2022	14	6	19	22	6,12	3,83	18,68	21,6	38,72	21,00	1,21	5,76
10	Essai Maq.	21.12.2022	24	6	19	22	6,15	3,87	20,52	23,02	39,59	19,98	1,13	5,66
11	Essai Maq.	05.01.2023	16	6	19	22	6,02	3,64	13,2	14,68	33,07	20,37	1,04	5,11
12														
13	Cal. Maq.	"Moyenne"	-	6	19	19	-	4,02	5	7,5	19,31	15	0,69	4,60
14	Méthode:	"mi-volume"	[min]	[min]	[min]	[min]	[Lit/min]	[Lit/min]	[°C]	[°C]	[°C]	[K]	[K]	[%]
15														
16	Cal. Rés.	"Moyenne"		[h]	[h]	[h]		[m3/h]	[°C]	[°C]	[°C]	[K]	[K]	[%]
17	Méthode:	"mi-volume"	-	1460	4380	4380	-	457,77	5	7,5	19,28	15	0,71	4,73
18	Cal. Rés.	Intégration	-	1460	4380	4380	-	457,77	5	7,5	19,28	15	0,71	4,73
19														
20			Charge	Charge	Perte	Perte	Perte	Perte	Energie	Perte	Perte	Pertes	Pertes	Efficacité
21			Thermique	Thermique	Thermique	Thermique	Thermique	Thermique	Thermique	Thermique	Thermique	Thermique	Thermique	Stockage
22			Brute	Nette	Chargemen	Chargemen	Stagnation	Stagnation	Déchargée	Déchargem	Déchargem	Nettes	Nettes	Nette
23			CTB	CTN	PTC	PTC	PTS	PTS	ETD	PTD	PTD	PTN	PTN	ESN
24	Type	Date			(CTB-CTN)	(PTC/CTB)		(PTS/CTN)			(PTD/CTN)	(PTS+PTD)	(PTN/CTN)	(ETD/CTN)
25	Essai/Calcul	[j:m:a]	[MJ]	[MJ]	[MJ]	[%]	[MJ]	[%]	[MJ]	[MJ]	[%]	[MJ]	[%]	[%]
26	Essai Maq.	24.11.2022	5,78	5,21	0,57	9,89	-	-	4,25	0,96	18,44	0,96	18,44	81,56
27	Essai Maq.	19.12.2022	6,98	5,18	1,80	25,84	0,27	5,14	4,47	0,50	9,65	0,77	14,79	86,40
28	Essai Maq.	20.12.2022	9,77	6,82	2,95	30,24	0,42	6,10	5,69	0,71	10,42	1,13	16,52	83,48
29	Essai Maq.	21.12.2022	13,85	6,77	7,08	51,11	0,39	5,78	5,16	0,86	12,71	1,25	18,50	76,29
30	Essai Maq.	21.12.2022	12,67	6,44	6,23	49,16	0,36	5,65	4,82	0,82	12,70	1,18	18,35	74,80
31	Essai Maq.	05.01.2023	9,05	6,57	2,49	27,49	0,33	5,09	5,37	0,77	11,76	1,11	16,85	81,75
32														
33	Cal. Maq.	"Moyenne"		(kWh)			(kWh)	[%]	(kWh)	(kWh)	[%]	(kWh)	[%]	[%]
34	Méthode:	"mi-volume"	-	1,34	-	-	0,07	5,22	1,20	0,14	10,45	0,21	15,67	89,55
35														
36	Cal. Rés.	"Moyenne"	(GWh)	(GWh)			(GWh)	[%]	(GWh)	(GWh)	[%]	(GWh)	[%]	[%]
37	Méthode:	"mi-volume"	35	35	-	-	2,00	5,71	31,17	3,81	10,89	5,81	16,60	89,06
38	Cal. Rés.	Intégration	35	35	-	-	2,00	5,71	29,36	3,62	10,34	5,62	16,05	83,89

Excel Table 32: Summary of thermal losses from the Reservoir and the ULISSE Mock-up (based on calculations by the theoretical model and experimental measurements on the Mock-up)

3.3.6 Numerical simulation of the ULISSE type Reservoir and the Mock-up

Generalities

Numerical simulation, using COMSOL Multiphysics software, is the third approach for determining the heat losses or conversely the efficiency of the seasonal energy-heat storage of the ULISSE Reservoir and for **validating the theoretical calculation model and the experimental Mock-up**.

At the current end of the ULISSE project's exploratory study, this has already been done in part for the full-scale Reservoir and in part for the Mock-up. The latter was done as part of Mr. Daniel Bello Mendes's final year *Master of Science in Engineering thesis* at HEPIA under the supervision of Professor Roland Rozsnyo.

The Mock-up was used to physically reproduce, on a reduced scale, the annual seasonal operating cycle, with and without summit water injection and extraction, distinguishing between a "static" phase (autumn stagnation) and two "dynamic" phases (summer loading and winter discharging).

On the basis of data from the real ULISSE Reservoir and the Mock-up, the interactions with the outside (IBC test tank vs. lake) were modelled and numerically simulated. The modelling and numerical simulation, using finite elements, should make it possible to compare the thermal evolution and heat dissipation of the Reservoir. In particular, this comparison was made with the data collected from temperature and flow measurements actually carried out in the laboratory on the physical Mock-up.

Prior to this student work, Professor Rozsnyo explored a first modelling approach directly from the full-scale Reservoir located in the lake (Figures 33 below).

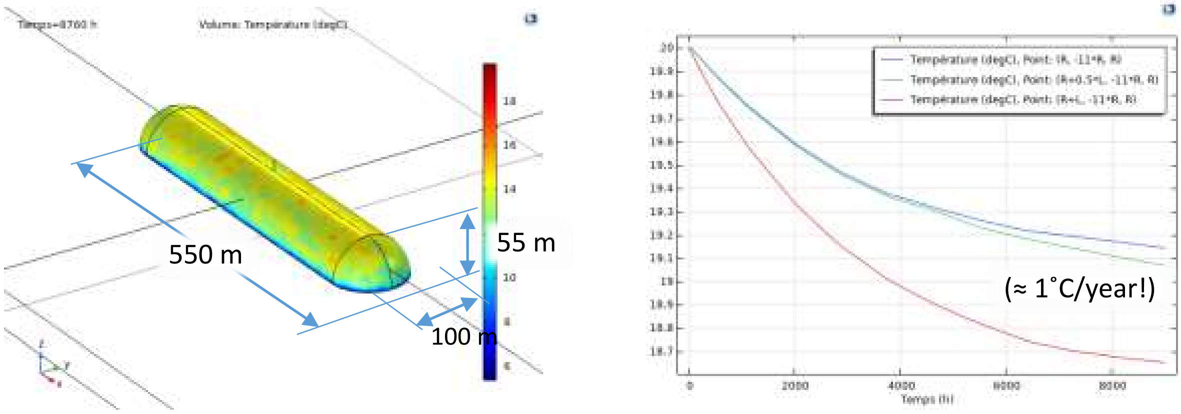
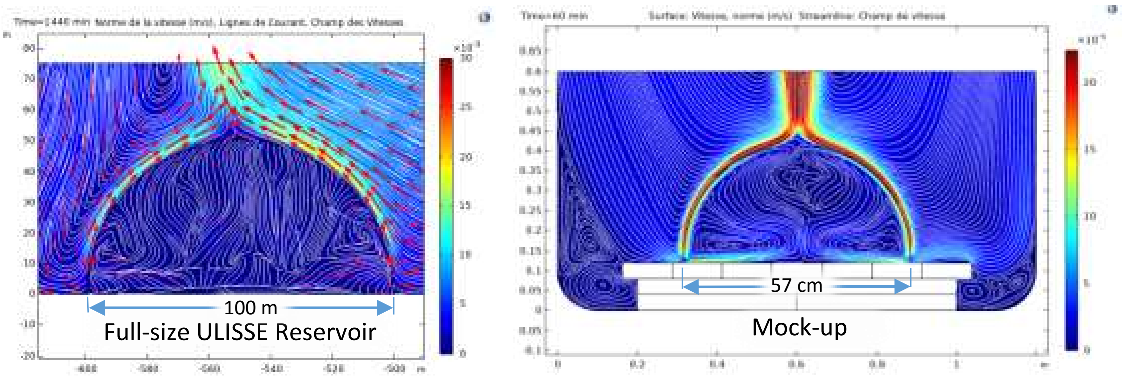


Figure 33: first modelling and numerical simulation of the full-size ULISSE Reservoir (2 M m³) and graph of temperature measurement points during "passive" cooling (without water injection or extraction) (≈ 1˚C/year!)

From the initial results of the numerical simulation, we can see the phenomenon of thermal convection inside the Reservoir and especially outside, i.e., the lake (figure 34 left). This phenomenon can also be seen on the Mock-up (figure 34 right). It clearly shows that heat loss from the ULISSE Reservoir would induce convection currents in the lake throughout the water column around the perimeter of the Reservoir.

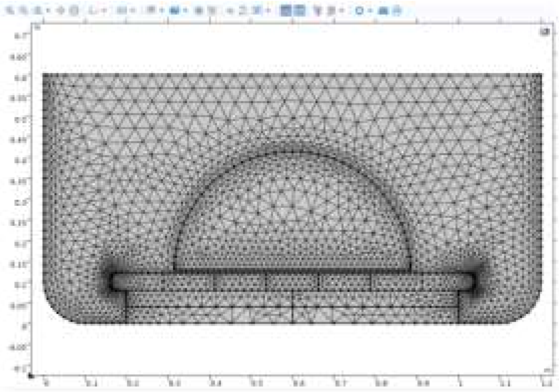


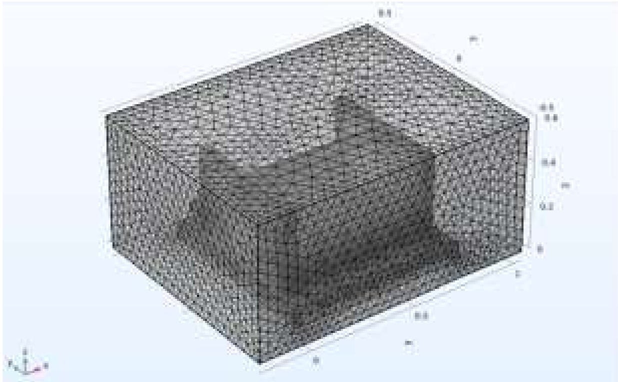
Figures 34: Cross-section showing thermal convection (water velocity fields) inside and outside the full-scale ULISSE Reservoir (left) and the Mock-up in the IBC tank (right).

If heat loss is decisive and to be minimized from an energy point of view, this can be a beneficial environmental aspect to promote the water mixing and essential oxygenation of the lake bottom; subject that is taken up in the chapter § 3.6.3 on the environmental impact of ULISSE.

Method and mesh for numerical simulation

Illustrated in Figure 35 below, the COMSOL solver uses the finite element method. In the finite element method, space and time are generally discretised separately: space is subdivided into geometric elements known as meshes. Assuming that the solution is known at the nodes of a mesh element, then the numerical solution on this element is obtained by interpolating the known values at the nodes. This is why the solutions depend on the quality and size of the mesh.





Figures 35: Automatic construction of the 2D (left) and 3D (right) mesh by COMSOL for the ULISSE Mock-up

COMSOL offers automatic mesh construction based on the physics used. The user can then modify the size of the elements in order to refine (or not) the results obtained. For most of the cases studied, this automatic meshing method is used. Alternatively, certain physical cases may require you to construct the mesh yourself. This is useful, for example, for obtaining greater accuracy at specific points in the domain. Illustrated in Figure 36 below, in order to reduce the calculation time for the 3D simulation, a quarter of the Mock-up has been modelled, which should not influence the results due to the double symmetry of X and Y.

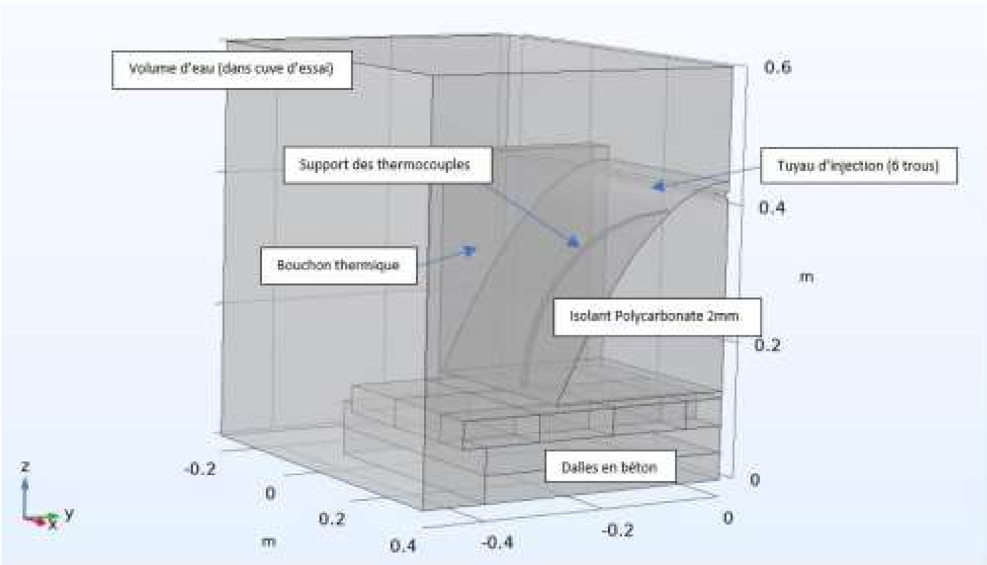


Figure 36: 3D digital geometry of the Mock-up for hydrothermal loading.
Only a quarter of the Mock-up is represented (double symmetry)

Interpretation of the first results of the numerical simulation

The first results of the numerical simulation of the Mock-up show a relatively good coherence with the experimental measurements. The simulation was made on a quarter of the model (18 litres) for a full volume of 72 litres. Illustrated in Figure 37 below, the loading time is certainly much too long (64 minutes instead of normally 6 min to correspond to the 2 months of Summer Loading). This was taken as similar to the first tests for comparison (with a total flow rate limited to 2,2 litres/min) and because of the limited initial capacity of the loading pump.

Normally to fill the model in 6 minutes, it would have been necessary to have a flow rate of 12 litres/min. However, this has no real influence on the "net" energy balance (without the thermal losses of loading).

For the Reservoir in the lake, the heat loss of the SL phase is less crucial because this can be compensated "at a lower cost" by the increase of the pumping rate or duration, supplied by the excess photovoltaic electricity, which will probably be in summer.

On the other hand, the times of the Autumnal Stagnation (AS) phase of 6 minutes and the Winter Discharging (WD) of 19 minutes are well respected and important for establishing the losses during the AS and WD phase. The latter is numerically simulated with an extraction flow rate of approximately 0.95 lit/min (3.8 lit/min for the full volume of the Model).

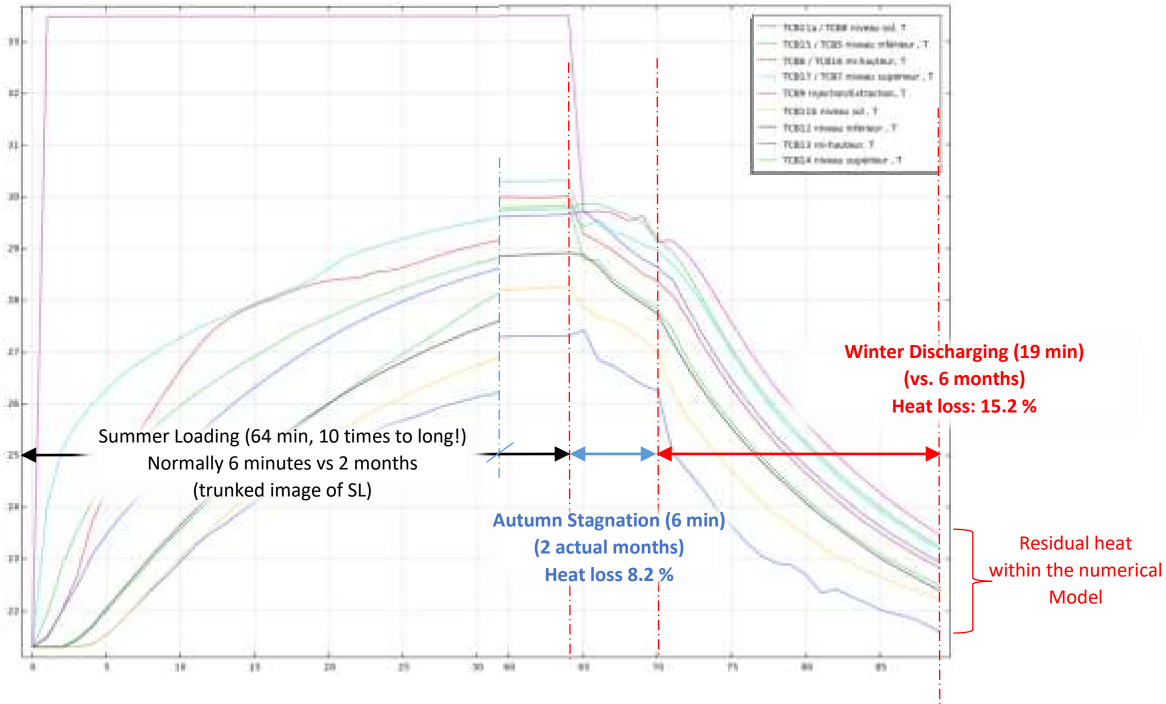


Figure 37: Temperature reading during the complete Summer Loading (64 min, 10 times too long!) vs. Stagnation & Discharging cycle obtained by numerical simulation of the ULISSE Mock-up (net storage efficiency 76.7 % for extraction equivalent to the volume of the Mock-up in 19 min.). There's still some heat left in the Mock-up!

At the start, the IBC tank (lake) and the Mock-up have a common temperature of approximately 21.3˚C. At the end of Summer Loading the Mock-up contains approximately 2.79 MJ of net heat energy (0.697 MJ for 1/4 of the Mock-up). At the end of the stagnation phase (6 min or 2 months in real life) the internal energy has fallen to 0.615 MJ, giving a heat loss of 8.2% (compared with 5.1 to 6.1% for real-life tests on the Mock-up). At the end of the unloading phase (19 minutes or 6 months), the residual internal energy was still 0.202 MJ.

Taking into account the energy extracted of 0.461 MJ for 1/4 of the Mock-up (1.843 MJ for the whole Mock-up), the net storage efficiency is 76.7%. This result is within the range of the results of the actual tests on the Mock-up, which are between 74.8% and 86.4%. (Table 32). An increase in the extraction flow rate or volume would make it possible to increase the recovery rate still further and approach the upper value of the said heat storage efficiency window.

The Figure 37 above shows also that stratification is maintained even after 19 minutes of extraction equivalent to the volume content of the Mock-up. This can also be seen in Figure 38 below. During the Winter Discharging phase there is a flow of heat both downwards and from the concrete slabs representing the lake bed (clearly visible colour gradient). These have stored heat during the loading and stagnation phases. In the present simulation, the loading phase was 10 times too long (64 instead of 6 minutes, Figure 37), which led to disproportionate thermal loading of the concrete bottom.

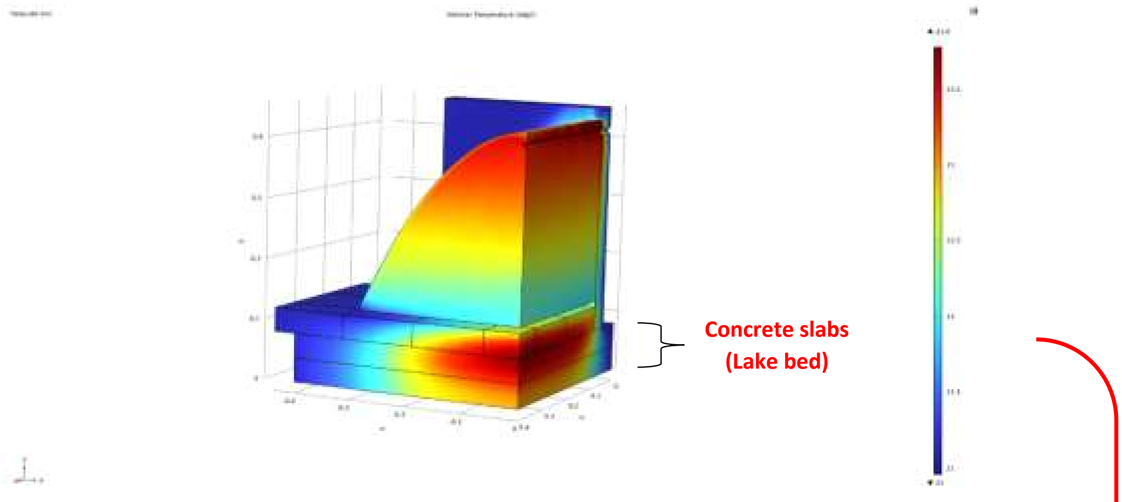


Figure 38: Graph representing ¼ of the Mock-up from the numerical simulation. It can be seen at the end of unloading (19 minutes) the equivalent of the volume of water in the Mock-up that there is still a temperature gradient in the Mock-up as well as in the ground (lake bottom). This indicates that the Mock-up still contains heat energy.

The warming of the bottom slab can also be seen in Figure 39 below, which corresponds to the last test on the real Mock-up on 5 January 2023.

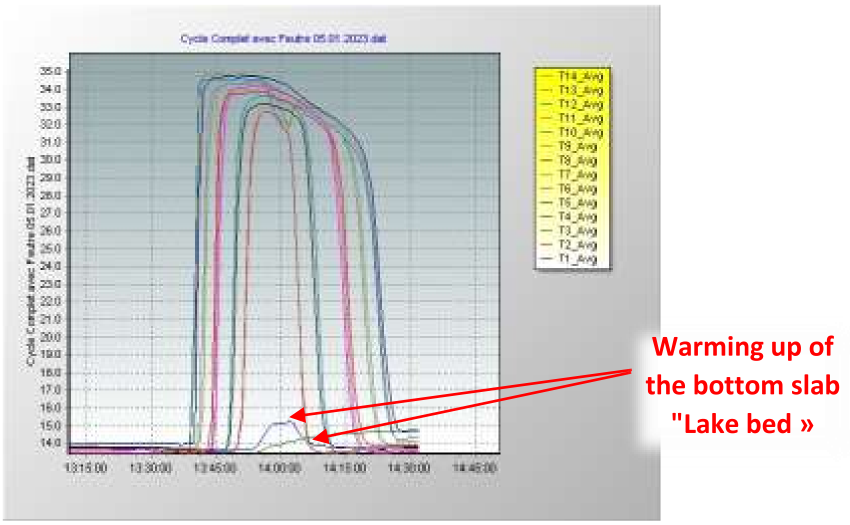


Figure 39: last test of the Mock-up (full cycle) of January 5, 2023

In conclusion, given the current state of progress of the numerical simulation and taking into account the simplifications introduced for the purposes of numerical modelling, it shows relatively good consistency with the actual tests carried out on the physical Mock-up. This applies both to heat losses during the stagnation phase and the discharging phase, as well as to the efficiency of seasonal thermal storage. For the real full-scale Reservoir, the simulation has not yet been completed. The numerical simulation work will have to be continued in the next stage, after this exploratory study of the ULISSE project.

3.4 Analysis of the GeniLac Thermal Lacustrine Network

The analysis of the energy performance of the ULISSE - CORSAIRE system is carried out on the basis of the TLN GeniLac and the public DWN in Geneva. A comparison is then made with alternative Thermal Networks powered by solar thermal collectors and earth pit/basin for seasonal heat storage (Appendix, Extended report, § 7.6.1).

3.4.1 Description of the GeniLac system

The TLN GeniLac is currently under construction and will be fully operational by 2035. Thanks to the thermal capacity of Lake Geneva, it will provide 245 GWh of air conditioning by the free cooling and 277 GWh of heating in the downtown of Geneva and the airport. Illustrated in Figure 40 below, the water is collected at a depth of 45 meters, at a temperature of around 7°C in summer and 5°C in winter. It's then transported by the main lake pumping station (Vengeron) in underground pipes to the connected buildings.

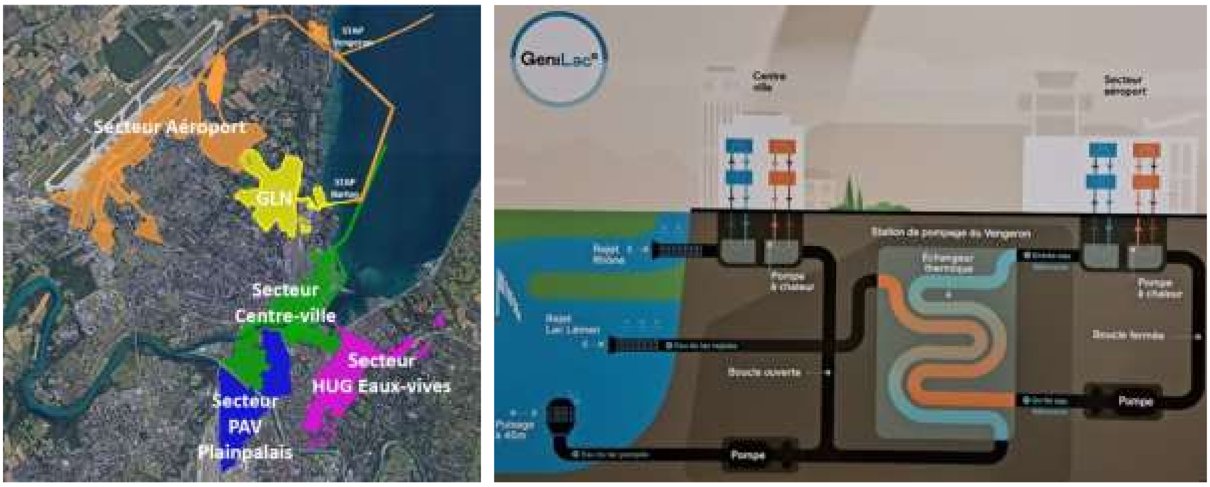


Figure 40: Schematic diagram of the GeniLac cooling and district heating system with Lake Geneva (Source: SIG)

For summer air conditioning the heat extracted from the buildings passed simply through heat exchangers (free cooling) and is then returned to the lake (or the Rhône downstream) at a temperature of around 12°C. Conversely, to heat the buildings (for space heating and domestic hot water) requires heat pumps (HP, powered by 70 GWh winter electricity, COP ≈ 3,5) to extract the heat from the lake water before it's returned to the lake cooled at around 2°C. The electricity consumption for air conditioning will be reduced by 70 GWh (COP free cooling: 18 vs 2,8 for conventional air conditioning) and CO_2 emissions reduced by 70,000 tonnes per year, linked to the substitution of fossil fuel. [7, 8, 9, 10, 11]

3.4.2 Lake Water Temperature Impacts

The summer air conditioning of the buildings, by free cooling (without heat pump), is very effective with water at around 7-8°C pumped from the bottom of the lake (hypolimnion zone) and returned to the lake at around 12-13°C. The draw-return temperature differential ΔT is approximately 5 K or even more depending on the epilimnion zone and the dispersion of the waste heat flow in the lake. The ratio between the cooling-energy supplied and the electricity for pumping lake water (COP) is announced by SIG at 18!

On the other hand, and in general, the extraction of heat from the lake for space heating in winter is more complex and less efficient, in particular due to the reduction of the temperature difference available by the lake (ΔT ≈ 3 ˚C) and which is then reduced by half to a third compared to summer, as is the temperature of the "cold source" for the heat pumps.

Hydraulic impact (lake water volume and flow rate)

At winter heat exchange equal to summer, the lower winter temperature difference (ΔT) must be compensated by a proportional increase in the volume of water pumping and circulation. This leads to proportional pressure losses (squared) of the flow rate and therefore the electrical energy absorbed by the hydraulic pumps is 5 to 10 times greater than that for summer cooling, which represents 1/4 of the total electricity consumption of the system. Added to this is a portion of gravitational energy linked to the difference in level lake-network and which would not be completely recovered by the turbines of the water returning to the lake.

Thermodynamic impact (COP performance of heat pumps)

The coefficient of performance (COPac) of the heat pump inversely follows the temperature of the "cold source", in this case that of the lake. For example, the electricity consumption of heat pumps decreases by approximately 23% for a 12°C increase in temperature at the lake water intake (Δ ≈ 2%/°C). The COPac also differs according to the temperature of the "hot source » or its use (space heating or DHW). It is nearly double for space heating (starting at 35˚C => COP = 4,93), compared to DHW (starting at 65˚C => COP = 2,73).

The space heating / DHW ratio influences the performance of the GeniLac network (COPac-mix, from 2,73 to 4,93). For the current state of the energy efficiency of the building stock (ECEEB-A), with a typical mix between the share of space heating and DHW of 70/30%, we would obtain an average winter COPac-mix of heat pumps of 3,97:

$$\text{COPac-mix medium} = 1/((0{,}7/\text{COP-heating}) + (0.3/\text{COP-DHW})) = 3{,}97\ [-] \qquad (10)$$

Since the energy challenge is less located in summer, unlike the structural deficit of electrical energy in winter, the study focused more on the operation of the TLN network in the winter semester.

Figure 41 below shows the average flows of water pumping from the lake and supply by the heat pumps of useful heat-energy for space heating and DHW in the winter semester (250 GWh-t, excluding 27 GWh-t of gas make-up). Heat pumps are installed in substations located in buildings with heat exchangers separating the heat pump circuit from the Thermal Lacustrine Network (GeniLac).

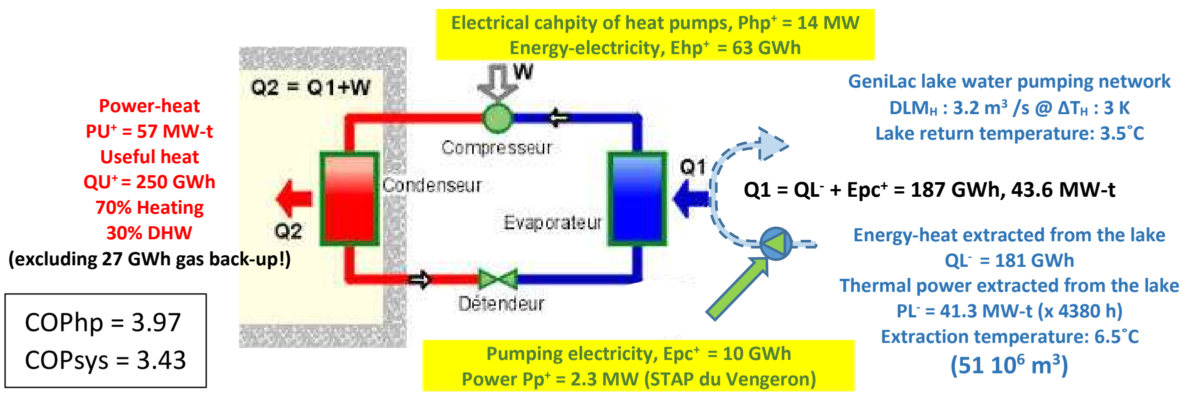


Figure 41: Diagram of winter water and energy flows for GeniLac heat pumps (ECEEB-A)

Consequence of the Climate Status and Energy Efficiency of Buildings in 2050

Based on the *ClimaBau - BFE 2017* study [3], it has been considered that Global Warming between now and 2050 will increase the need for cooling (Air Conditioning) by 20% and conversely will reduce Room Heating (RH) by 20%. In addition, improving the energy efficiency of buildings will reduce RH by a further 20%.

We have added the hypothesis (recommended for 2050) of the **widespread connection of washing machines and dishwashers to domestic hot water (DHW), using heat pumps**, which will increase demand by a further 20%. This is on the grounds that it would be paradoxical to continue heating the water in these household appliances by the "joule effect" (direct degradation of electricity into heat).

The concomitant change in the *energy efficiency of buildings* (CEEB-2050) in residential buildings will therefore reduce (in equal parts) the Heating Demand Index specifically for room Heating (HDI-H), expressed in MJ/m² ERS (Energy Reference Surface), by around 40%.

The ECEEB-2050 will bring the room heating / DHW mix (Mix-H/W) ratio closer to balance (55/45) and further strengthened over time by supplying household appliances to DHW. It will also have the effect of lowering the future winter performance of the Thermal Lacustrine Networks (TLN) such as GeniLac. There is therefore a huge challenge or impact on the method of production of domestic hot water (DHW)!

With a 40% reduction in HDI-H, the "Mix-H/W" falls from 70/30% (as it stands today) to 55/45% in 2050. As a result, the spatial energy density (J/m²) of TLN networks (such as GeniLac) will fall by just 22%, due to the concomitant 20% increase in DHW demand.

To maintain the overall supply of useful heat (Qu^+: 250 GWh for GeniLac), TLN networks will have to expand spatially to cover a larger urban area or a greater number of building connections and users (≈ 30%).

3.4.3 Integration of ULISSE into the TLN GeniLac Network

By using ULISSE during the winter semester to capture lake water at an average temperature of 19°C instead of 6.5°C (GeniLac alone), i.e., an average gain of 12.5°C in the cold source (Tf), the energy balance is improved: 1) at the level of the COPac of the heat pumps and 2) at the level of the hydraulic pumps (reduced pressure drops according to the square of the reduction in flow rate). In the Actual Climate Energy Efficiency state of the building stock (ECEEB-A), compared to GeniLac alone, the energy and electrical power of GeniLac with ULISSE are reduced by 48%. In August 2023 the upper layer of the Lake Geneva reached 25°C (Figure 42 below). How much in 2050? The thermal loading capacity and the global performance (COPsys) of ULISSE will at least be increased.

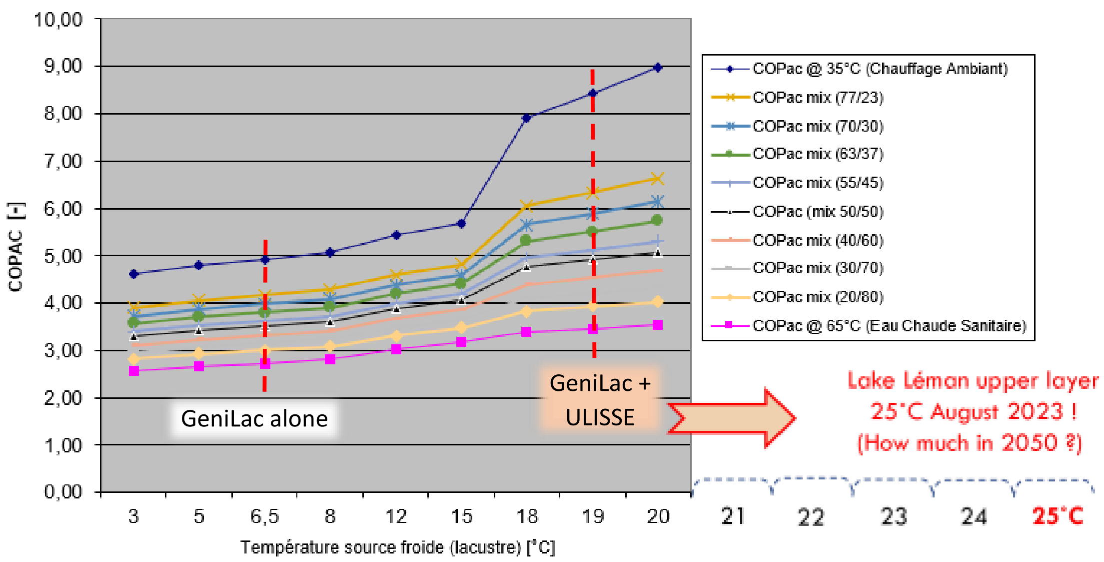


Fig. 42: Performance of heat pumps (COPac) according to the cold source temperature and the Mix RH / DHW

3.4.4 Association of CORSAIRE free heating with ULISSE at GeniLac

Illustrated in Figure 43 below, the winter temperature correction of the Drinking Water Network (DWN) is mainly carried out via a plate Heat Exchanger (HE) located in a Heat Exchange Station (HES). Drinking water is deglazed by counter-current exchange with the heat flow from the primary water circuit (thermal source). This heat source is in this case the ULISSE Reservoirs. It can also consist of other thermal sources at low temperatures, such as water leaving a wastewater treatment plant (WTP). [4]

The exchanger is located after the Drinking Water Station (DWS) and at the outlet of the water pumping and distribution station (WPDS) in the DWN. In this way, the drinking water is always at a pressure above that of the primary water (of the heat source) in order to avoid contamination in the event of a leak in the exchanger. The pressure of the Drinking Water Tower (DWT) also provides hydrostatic overpressure even when the DWP is off.

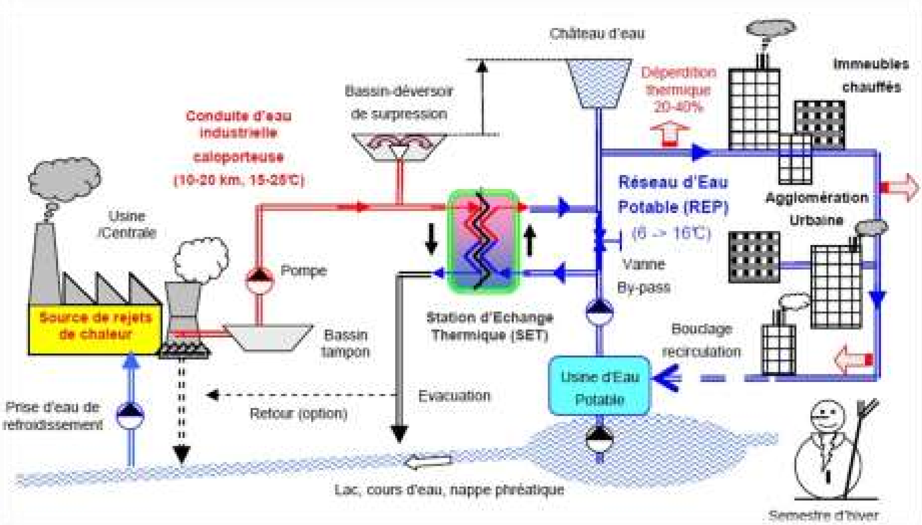


Figure 43: General principle of the CORSAIRE process (free heating, without HP) with industrial waste heat source

3.4.5 Variant of integration of CORSAIRE free heating in the building

A variant of the CORSAIRE free heating process consists of placing the Heat Exchanger inside the Building Technical Rooms (BTR). This does not modify the performance of the HPs and therefore the COPac remains at 5,51. The only difference in this case is that the urban DWN is not used for the free heating. The thermal input for the free heating (Qcor) is routed by the TLN GeniLac itself, which increases the volume of lake water in circulation by 20%, thus increasing from approximately 10 to 12 M m^3. Since hydraulic pumping energy (EPH) is less than 1% of that of heat pumps (Epac), the increase in hydraulic energy remains negligible. As a result, the COPsys of the TLN increases from 5,46 to 6,32!

This variant (internal free heating by the TLN) is considered here because the free heating by the public DWN is not necessarily implemented and because the DWN applies to the entire urban agglomeration, well beyond the capacity of the TLN network GeniLac. For example, the DWN of Geneva canton is more than 1'200 km long, 40 times larger than the GeniLac network (30 km). The supply of CORSAIRE via the urban DWN (Figure 44 below) involves practically no additional electrical energy, other than that linked to pressure drops in the CORSAIRE Heat Exchanger (CHE). This, given that drinking water is transported and distributed to all buildings in the city anyway.

3.4.6 Conclusions for the GeniLac Thermal Lacustrine Network

The analysis of the association of ULISSE and CORSAIRE with the TLN GeniLac (taken as an example), compared the current state of the GeniLac system alone with that in 2050. It took into account the consequences of global warming and the planned improvements the energy efficiency of buildings (Climate Energy Efficiency State of Building stock, ECEEB). It has been considered that global warming (+ 2˚C in 50 years) by 2050 increases the need for cooling (air conditioning) by 20% and "passively" reduces space heating by 20%. In addition, improving the building's energy efficiency "actively" reduces again by an additional 20%.

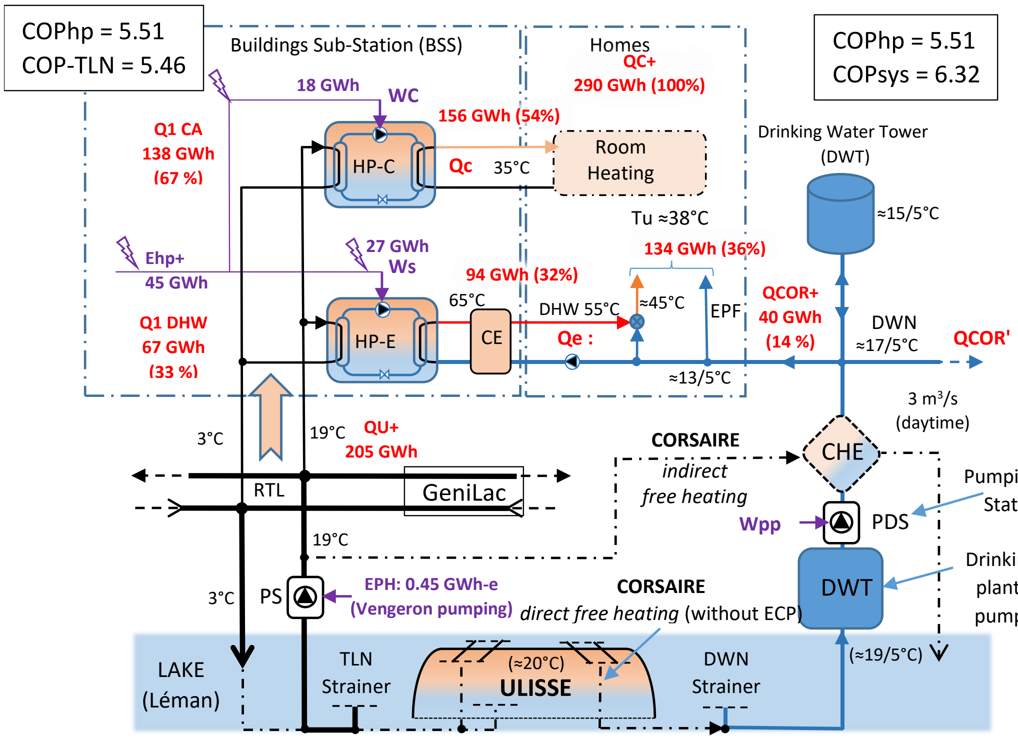


Figure 44: Combination of the TLN GeniLac network in the winter semester with ULISSE & CORSAIRE-DWN (ECEEB-2050)

Finally, **it was considered that in 2050 the connection of all washing machines and dishwashers to Domestic Hot Water (DHW)** will further increase the heat demand at the TLN by 20%, as well as the CORSAIRE free heating supplying 30% DHW (ECEEB-2050). As a result, the joint evolutions of the ECEEB modify the heat demand index (HDI) in MJ/m² ERS (Energy Reference Surface). Specifically, the HDI for Summer Cooling increases and that for Winter Heating decreases.

From the point of view of the building's energy performance, winter electrical energy from the TLN network (Esys) for space heating and DHW will decrease by 50% in 2050 thanks to the combination of ULISSE and CORSAIRE free heating. This is valid Externally by the urban DWN or Internally to the building or the TLN with or without the extension of the TLN network.

The electrical energy gain for the TLN network has been calculated here (conservatively) with a moderate cold source at 19˚C; this with the ULISSE Reservoirs initially charged at 20˚C by the lake upper layer water heated by the summer sun The water capture and storage temperature can be higher (> 20˚C), especialy in the future by the Global Warming impacting also the temperature of the lakes (ex. Figure 40), or even come from the air conditioning return or other thermal waste sources (WTP, etc.).

In other words, ULISSE and CORSAIRE free heating can potentially reduce the winter electricity consumption of TLN networks such as GeniLac by more than half.

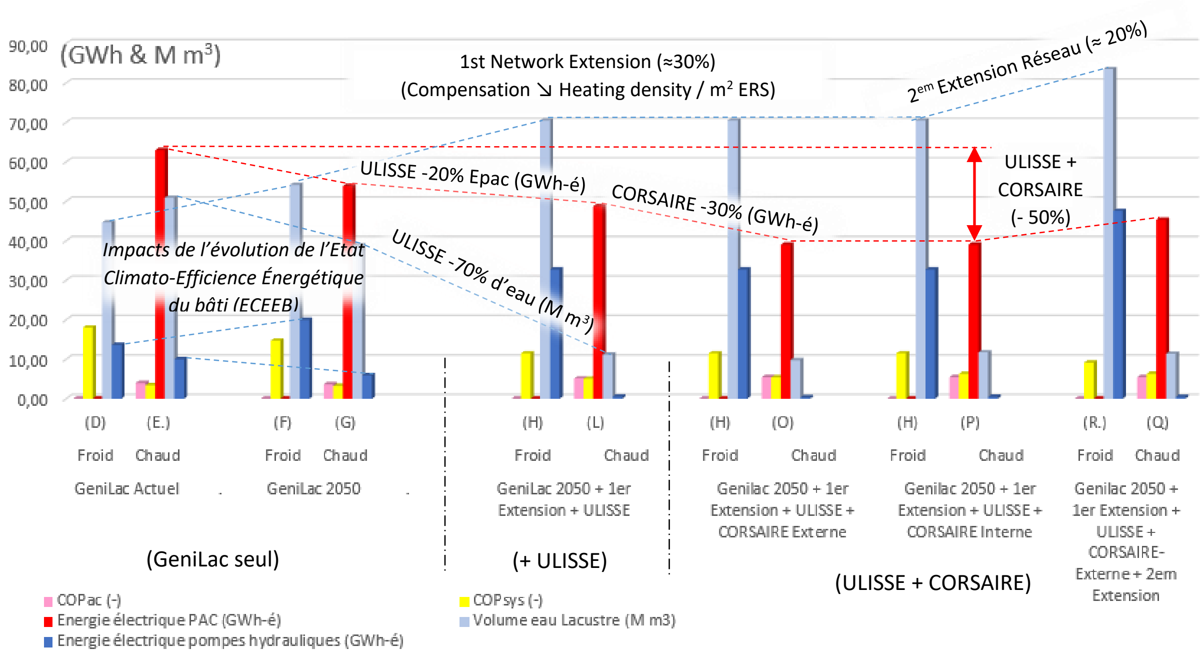


Figure 45: Energy comparison of cold (free-cooling) and heating (hot), associated with the volume of lake water (M m^3) as well as the electricity (GWh) of the hydraulic and heat pumps applied at GeniLac alone and with ULISSE and CORSAIRE

For GeniLac and the Canton of Geneva, the integration of ULISSE into GeniLac represents winter electricity savings of 40 GWh, or nearly 20% of the winter production of the Verbois hydroelectric powerplant. Based on the cost price of hydroelectric energy in 2050 from the AES study [16], between a river- and storage-hydropower plant, respectively 19 and 32 ct/kWh (190 and 320 k CHF/GWh) the financial savings of the 40 GWh electricity avoided for the canton of Geneva would be between 7,6 and 12,8 million CHF/year.

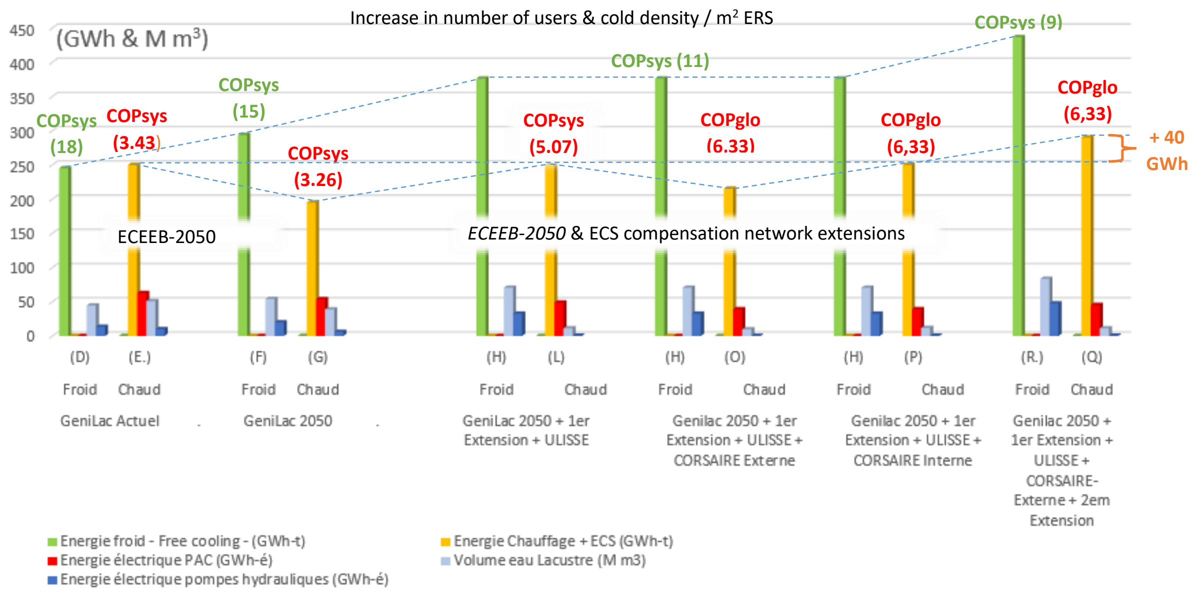


Figure 46: Comparison of energy flows (GWh) and circulating lake water (M m^3) for cooling (free-cooling) and heating (hot), using the Thermal Lacustrine Network (TLN) applied to GeniLac - alone and with ULISSE + CORSAIRE (free-heating).

3.4.7 Connection of the TLN GeniLac to the ULISSE Reservoirs

The CORSAIRE process concerns the entire DWN of the canton of Geneva (> 1’200 km). Its thermal source can also come from industrial thermal discharges, p. ex. the main wastewater treatment plant in the canton, the Aïre WTP (2 m^3/s). CORSAIRE with the Geneva urban DWN could supply during the winter semester of the order of 500 GWh-t net directly to all the buildings, i.e. double that of GeniLac, and almost without additional infrastructure. [6] The “internal” CORSAIRE contribution to the TLN Genilac network is limited.

For the supply during the winter semester of 250 GWh-t of GeniLac, with "internal" ULISSE and CORSAIRE (the "free heating" heat exchanger placed at the start of the TLN or at the drinking water inlet cold in the connected buildings), the volume of temperate water required for the heat pumps is 12 M m^3 **(Appendix, Extended report, Tab. 5.12, line 26, column J-Q,)**. This corresponds to 6 ULISSE reservoirs of 2 M m^3 each, with an average lake flow (DLM, 25-Q) of 0.75 m^3/s and a maximum of 1 m^3/s at the coldest of winter (DLP, 24-Q).

Illustrated in Figure 47 below, the laying depth of the ULISSE Reservoirss on the lake bottom is approximately 65 m. In the Petit-Lac, between the Versoix – Hermance, the depth varies from 60 to 75 m. A location for the 6 ULISSE Reservoirs would be possible near Anières, on the central axis of the Petit lac (Geneva-Vaud border).

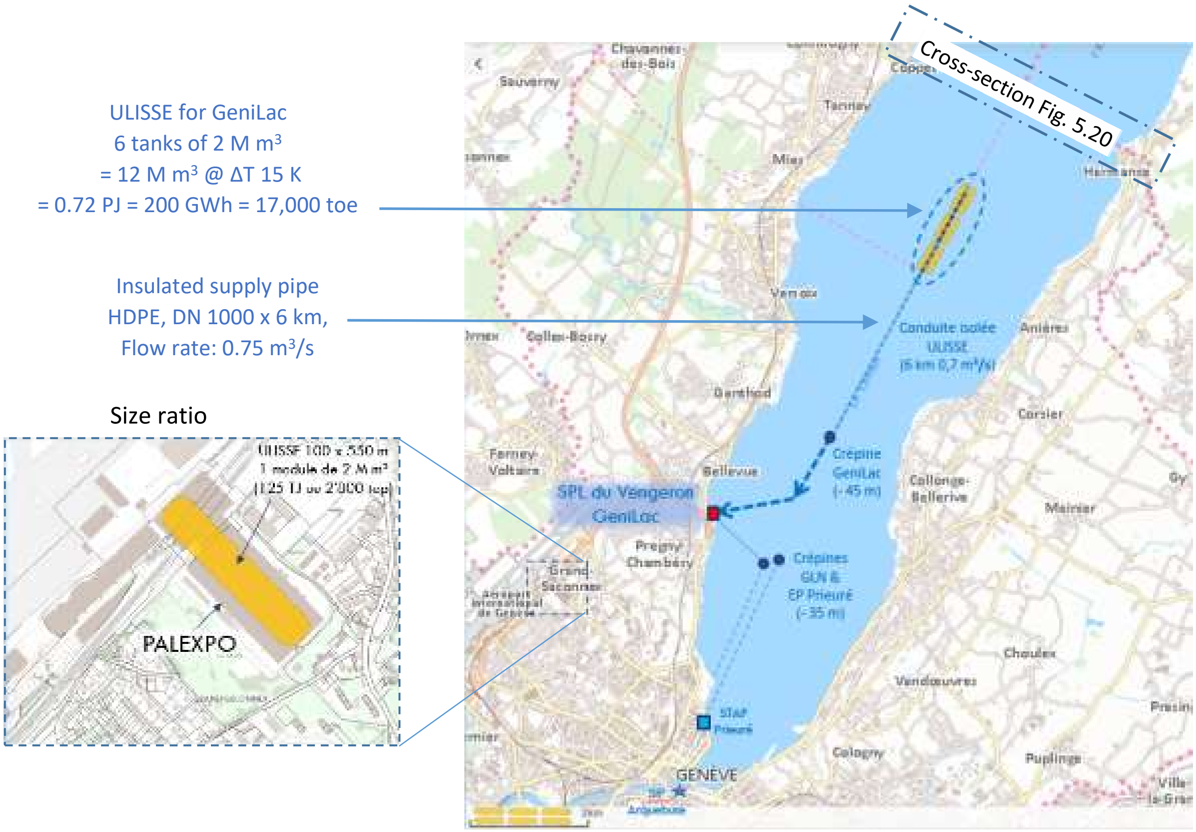


Figure 47: Location of the 6 ULSSE Reservoirs in the Petit-Lac Léman for GeniLac and in conjunction with the pump station.

The distance from the ULISSE Reservoirs to the GeniLac lake pumping station (LPS) is approximately 6 km and 4 km from the GeniLac suction strainer. The connecting pipe is therefore approximately 6 km long. With a nominal diameter (DN) of 1 m and a hydraulic flow (Dh) of 0.75 m^3/s, the hydraulic head losses in the HDPE (High Density Polyethylene) supply pipe are approximately 1 m w.c. (10^{-4} Pa) per km.

Content of the 6 km length of the pipe, the fittings and bends connecting the internal networks to the reservoirs as well as the suction strainers, the total pressure drop (Δp) in the hydraulic circuit is approximately 10 m C.E. (10^{-5} Pa or 1 bar). The hydraulic power (Ph) required for the circulation of water in the adduction pipe is the product of the pressure drop (Δp) with the hydraulic flow rate (Dh):

$$Ph = \Delta p * Dh = 10^4 \text{ kg/m}^2 * 0.75 \text{ m}^3/\text{s} = 7{,}500 \text{ [kg.m/s] or } 73.5 \text{ [kW]} \quad (11)$$

The hydraulic energy (Eh) is the product of power over time (4’380h) => 0.32 [GWh] (12)

Thermal insulation of the connecting pipe

Illustrated in Figures 48 and 49, the DN 1000 mm HDPE connection pipe is a pre-insulated pipe of the “COOL-FIT 4.0 by +GF+” type. This type of tubing is typically used for commercial and industrial refrigeration applications. The PE base material makes it particularly resistant to corrosion and insensitive to contact with water. Its smooth surface gives it low pressure drops (Δp). The maximum size (Nominal Diameter) available for COOL-FIT 4.0 is currently DN 450 (mm). It has an insulation thickness (GF HE foam) of 4 cm with a heat transfer coefficient (λi) of 0.026 W/m.K (source GF). The standard manufacturing unit length is 12 m. The different sections of pipe are joined by electrothermal welding or using bolted connections. A special version in DN 1000, possibly with a different insulation thickness, is essential (Figure 49).

Fig. 48: Pre-insulated HDPE pipe type COOL-FIT 4.0 from +GF

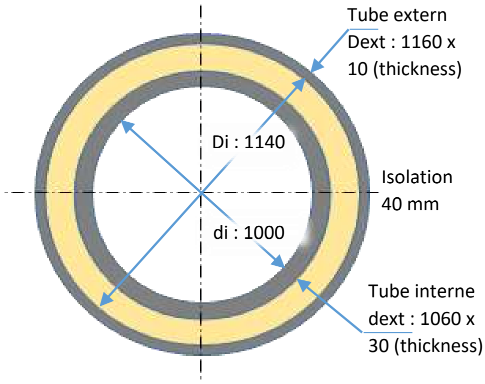


Fig. 49: Theoretical dimensions for DN 1000 pipe (mm)

Calculating heat loss from the supply pipe

The thermal power (Pt) dissipated by the supply pipe (DN 1000 x 6 km) is produced by the difference in temperature (ΔT) between that at the bottom of the lake (TL) and that of the water coming from the ULISSE reservoirs (TU). It is also a function of the circular conductivity (Kc) of the triple-layer pipe (PEint/Isol/PEext):

$$Pt = \Delta T * Kcl = (TU-TL) * Kcl = 15 \text{ K} * 17 \text{ KW/K} = 255 \text{ [KW]} \quad (13)$$

where $Kc = 2.\pi.L * \left(\lambda / \ln.(Rext/Rint)\right) \Rightarrow 2.\pi.L * \left((\ln. R2/R1)/\lambda pe) + (\ln. R3/R2)/\lambda i) + (\ln. R4/R3)/\lambda pe)\right)$ = 17 [KW/K].

where R1 = di/2 = 0.5 m; R2 = dext/2 = 0.53 m; R3 = Di/2 = 0.57 m; R4 = Di/2 = 0.58 m

The thermal energy (Qt) is the product of power and time (4,380h), i.e., 1.12 [GWh]. (14)

Transporting, immersing and laying the supply pipe on the lake bed

Immersing and laying the supply pipe on the lake bed, at a depth of around 70 m, subjected it to a hydrostatic pressure of 7.10^5 Pa (7 bar). The HDPE is perfectly resistant to this pressure level, which is balanced on both sides of the internal/external walls. The thermal insulation (GF HE foam) is also subject to this compression pressure, which should be bearable, and is not normally exposed to water. However, water intrusion into the insulation would affect its thermal properties (λi), or even damage the base material in the long term.

One way of preventing the parasitic introduction of water, causing by a crack in the wall of the inner or outer HDPE casing, would be to apply a slight overpressure of air or nitrogen between the tubes in the insulation. This would follow the same principle of protection by air pressurisation (§ 3.1.7, Figure 14) as for the enclosures of the submersible pump units of the summer loading system for ULISSE Reservoirs.

The procedure for laying the high-density polyethylene (HDPE) feeder pipe is very similar to that for the “Morges-Lac” (Lake Geneva) network or the Toronto DLWC (Figures 50 and 51 below) [51, 52, 53]. The pipe is assembled by thermoelectric welding and is simply floated onto the lake, with its concrete blocks already attached for ballasting on the lake bed. For the operation, the pipe is plugged at the ends to keep it empty of water. Once there, it is progressively filled with water and lowered to the lake bed.

Fig. 50 Transport (Lake Ontario) of the HDPE pipe (Ø 1.6 m x 15 km!) for pumping and supplying water of the Deep Lake Water Cooling (DLWC) system in the Canadian city of Toronto (Enwave image)

Fig. 51: Laying of the 1,500 m HDPE pipe of the Morges-Lac network at a depth of almost 45 m at the level of the suction strainer (production: 3.3 GWh for heating and 1 GWh for cooling).

Laying 15 km of DN 1600 (!) pipes at a depth of 80 m in Lake Ontario in 2003 cost 50 million dollars. Transposed 20 years later, to the 6 km for GeniLac (DN 1000 x 6 km) in Petit Lac Léman (Figure 47), this would represent proportionally CHF 12.5 million, or about CHF 2 million/km of pipe.

3.5 National potential for setting up and saving electricity by ULISSE and CORSAIRE

3.5.1 National potential of ULISSE and CORSAIRE "internally" (via the TLN)

At the stage of this exploratory study, with fragmentary data on the state and evolution of demographics and the situation of urban agglomerations, the estimate of the potential of ULISSE and CORSAIRE can only be approximate, at best a target for 2050. This is not to say that there will be nothing left to do after 2050, or that climate change will stop. Nevertheless, we can categorise three scenarios and put forward hypotheses that will have to be validated later.

In 2050 (ECEEB), assuming widespread ambient heating and DHW production via TLN networks in the "*urban agglomerations of the 15 Great Lakes*" (1/4 of the Swiss population: Qc = 50 PJ/year of heat for a total of 200 TJ), the winter electrical energy (Esys) to power heat pumps (HP) and hydro-lacustrine pumps (PHL) would be 15.3 PJ or 6.4 TWh, with COPsys = 3.26 **(**Appendix, Extended report, Tab. 5.12, G19).

Combining these TLN networks with ULISSE and CORSAIRE (Internal/External) would result in a gain of 50% with a COPbât = 6.34 (Appendix, Extended report, Tab. 5.12, O-20), i.e., a winter electrical energy saving of 2.1 TWh (ΔEsys):

ΔEsys = (Qc / COPbât) - (Qc / COPsys) = (50 PJ/6.34) - (50 PJ/3.26) = 7.45 [PJ] or 2.07 [TWh] (15)

With a gain equivalent to the GeniLac TLN (≈ 40 GWh-e with 12 M m^3 of ULISSE Reservoirs), the 2.07 TWh would require 310 ULISSE Reservoirs of 2 M m^3 each:

Number of Reservoirs (NUR @ 2 M m^3) = (2.07 TWh / 40 GWh) * 12 M m^3 = 621 M m^3 = 310 (16)

The 310 ULISSE Reservoirs would total almost 17 km^2 of (unseen) surface area on the lake bed, i.e., 0.83% of the total surface area of the 15 large lakes (> 10 km^2). These large lakes have a total surface area of 2,024 km^2 of which 1,233 km^2 are in Switzerland. The 621 M m^3 of water stored in the 310 ULISSE Reservoirs represents a 30 cm thick layer of water spread over the 2,024 km^2 of these 15 largest lakes shown on the map of Switzerland in Figure 52 below.

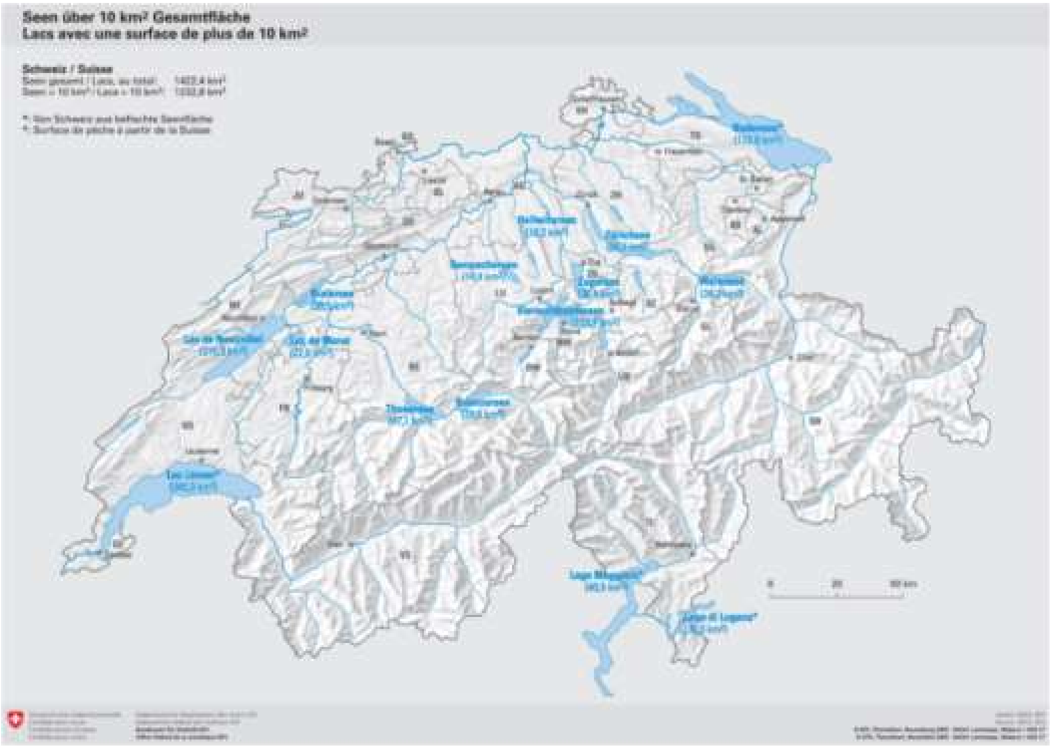


Figure 52: 15 largest Swiss lakes, surface area greater than 10 km^2, potentially compatibles for ULISSE Reservoirs (source: OFS)

To put this into perspective, the 17 km² of (invisible) right-of-way on the lake bed of 310 ULISSE Reservoirs (NUR) represent 11% of the 150 km² surface area of the 30 GW-p of photovoltaic panels still to be installed to supply the 30 TWh of additional electrical energy by 2050 (150 km² ≈ 1/4 of the 580 km² surface area of Lake Geneva).

A distribution of 310 ULISSE Reservoirs over the 15 largest Swiss lakes represents an average of approximately 21 Reservoirs/lake. More precisely, in Table 53 below, we can establish a first theoretical distribution of the Number of ULISSE Reservoirs (NUR) in proportion to the surface area of these 15 large lakes. However, this is not necessarily a sufficient criterion. It also needs to be assessed in terms of the population living near the lakes and potentially benefiting from the ULISSE system, in particular through the TLN networks.

	Nom	Volume par lac (km³)	Surface totale (km²)	Surface Suisse (km²)	Surface Suisse (% vs les lacs)	Répart. ULISSE (NRU/surf.CH. lac)	Répart. ULISSE (NRU / habitants)	Volume ULISSE (% vs lac)	Surface ULISSE (% vs lac)
1	Lac Léman (CH, FR)	89	580	345,3	28,7	87	?	0,20	0,81
2	Lac de Constance (CH, D, AT)	48	539	172,9	26,6	43	?	0,18	0,44
3	Lac de Neuchâtel	14	215	215	10,6	54	?	0,77	1,36
4	Lac Majeur (CH, IT)	37	212	40,5	10,5	10	?	0,06	0,26
5	Lac des Quatre Cantons	11,8	114	114	5,6	29	?	0,49	1,36
6	Lac de Zurich	3,9	88	88	4,3	22	?	1,13	1,36
7	Lac de Lugano (CH, IT)	6,5	49	30	2,4	8	?	0,23	0,83
8	Lac de Thoune	6,5	48	48	2,4	12	?	0,37	1,36
9	Lac de Bienne	1,1	40	40	2,0	10	?	1,80	1,36
10	Lac de Zoug	3,2	38	38	1,9	10	?	0,60	1,36
11	Lac de Brienz	5,2	30	30	1,5	8	?	0,29	1,36
12	Lac de Walenstadt	2,5	24	24	1,2	6	?	0,48	1,36
13	Lac de Morat	0,6	23	23	1,1	6	?	2,10	1,36
14	Lac de Sempach	0,7	14	14	0,7	4	?	1,07	1,36
15	Lac de Hallwil	0,3	10	10	0,5	3	?	1,80	1,36
	Totaux :	230,2	2 024	1 233	100,00%	310	310	0,20	0,83

Table 53: Distribution of the Number of ULISSE Reservoirs (NUR) in the 15 large lakes in proportion to the surfaces (What about a distribution according to the local population?)

As an example, for Lake Geneva, illustrated in Figure 54 below, the bathymetric map shows that the lake bed has a surface area of 68 km² (green colour) where the depth is between 50 and 75 m, equivalent to 1,200 ULISSE Reservoirs with a unit right-of-way of 54,000 m² on the lake bed. The actual installation of 87 ULISSE Reservoirs in Lake Geneva (Table 51, line 1) would represent 4.7 km2 or 0.8% of the lake bed (580 km2) and 0.2% of the volume (89 109 m3), invisibly and neutrally for navigation (e.g., boats of the Compagnie Générale de Navigation on Lake Geneva).

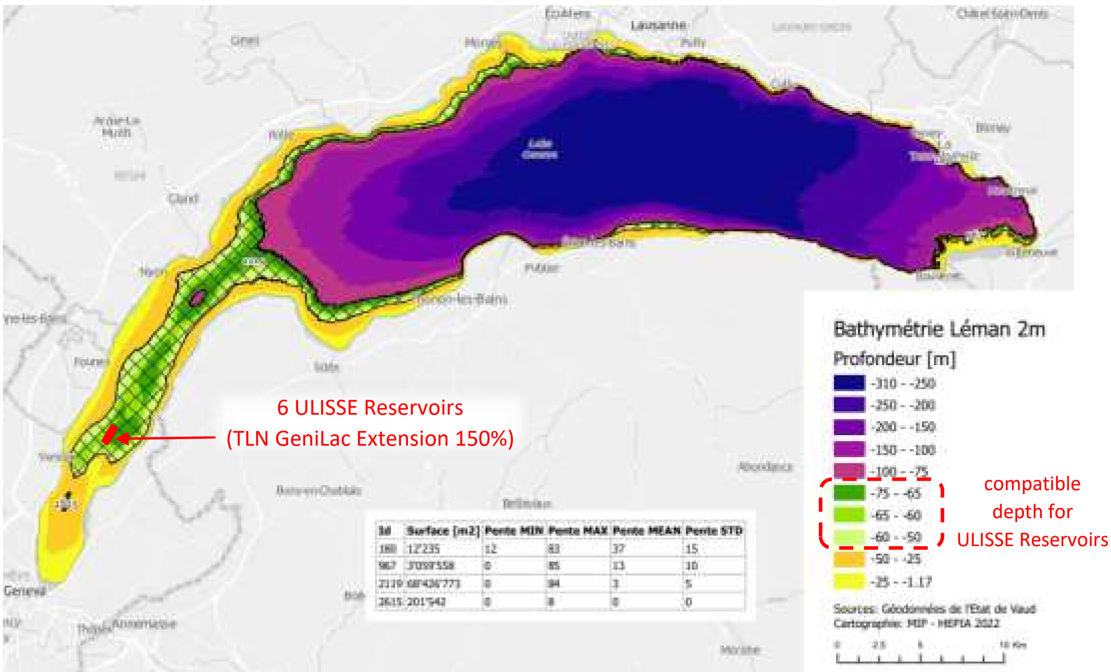


Fig. 54: Bathymetry of Lake Geneva. Green zones (50-75m): compatible depth for ULISSE Reservoirs (green zone area: 68 M m² => 1'200 ULISSE Reservoirs @ 54'000 m²) (source map: Prof. Alain Dubois, HEPIA 2022).

3.5.2 National CORSAIRE potential via the DWN excluding TLN or lake regions

As described above, the CORSAIRE free heating process can exploit waste heat produced during the winter months, such as waste heat from wastewater treatment plants (WTPs). [4] The use of DWN by CORSAIRE upstream with heat from WTPs is therefore quite logical, especially as their respective flows are concomitant.

CORSAIRE free heating does not therefore necessarily require seasonal storage of the ULISSE type or infrastructure other than the existing DWN. It can therefore be used outside the regions of the large lakes and be accessible to all other urban agglomerations with a sufficient density compatible with the installation of the CORSAIRE heat exchanger on the urban DWN.

For a first estimate of the potential, we make the conservative assumption that in 2050 half (P1: 0.5) of the buildings are not connected or are unsuitable for the ULISSE and CORSAIRE systems, for various reasons (density too low, building too far away, insufficient or unsuitable heat source, etc.). If we deduct 1/4 (P2: 0.25) of the buildings already benefiting from ULISSE (lake regions), this leaves 1/4 (P3: 0.25 = 1 - P1 - P2) of the Swiss population benefiting from 30% (P5: 0.3) of the energy for DHW (Q-ECS3) via the CORSAIRE free heating and urban DWN.

While for the entire Swiss population, the heat demand for room heating and DHW (Qcn) in 2050 is 200 PJ, the demand for the part (P3) is: Qc3 = 0.25 * (Qcn) = 50 PJ. According to the MixH/W in Table 5.12 (Appendix, Extended report), 45% (P4: 0.45) of the heat Qc3 is used for Q-ECS3 = 0.45 * Qc3 = 22.5 PJ. Finally, the CORSAIRE contribution (Q-cor) corresponds to 30% (P5: 0.3) of the heat for Q-ECS3.

$$\text{Q-cor} = \text{Qcn} * \text{P3} * \text{P4} * \text{P5} = 200 \text{ PJ} * 0.25 * 0.45 * 0.3 = 6.75 \quad \text{[PJ]} \qquad (17)$$

The 6.75 PJ of heat supplied by the CORSAIRE free heating system for DHW (Q-ECS3) would (without CORSAIRE) normally be produced by the heat pumps. With a COPhp-dhw of 2.73 (assumed to be identical to the TLN heat pumps in Table 4.1, E-7, Appendix, Extended report), they would have absorbed 1.15 TWh electricity. This is therefore as much electrical energy saved (ΔEcor) by the net supply of Q-ECS3 in CORSAIRE free heating:

$$\Delta\text{Ecor} = 6.75 \text{ PJ} / 2.73) = \quad 2.47 \text{ [PJ]} \quad 0.69 \quad \text{[TWh]} \qquad (18)$$

3.5.3 National potential for electricity savings and investment by ULISSE and CORSAIRE

With these conservative assumptions (or objectives) for 2050, 1/4 of the Swiss population (lake regions) would benefit from ULISSE associated with free heating via the TLN networks (internal CORSAIRE) and another 1/4 of the population (excluding lake regions) would benefit from CORSAIRE alone, in external free heating via urban DWNs.

The ULISSE (17) and CORSAIRE (18) ensemble, by providing 57 PJ of heat (i.e., nearly 30% of national needs), therefore potentially constitutes a net Winter Electricity Saving (WES) of 2,76 TWh-é net.

$$\text{WES} = \Delta\text{Esys} + \Delta\text{Eecs} = 2{,}07 \text{ TWh} + 0.69 \text{ TWh} = \quad 2{,}76 \quad \text{[TWh-e]} \qquad (19)$$

Taking into account the losses of transformation and transport of the electricity in winter, of 10% (7% on annual average), the 2.76 TWh-e net require a gross production of 3 TWh-e or 1/3 of the deficit electricity winter structure in 2050 (9 TWh).

This is the equivalent of the gross winter production of two hydropower complexes as Grande-Dixence in 2050 or equivalent of the annual electricity consumption of the Swiss electric public transport (railways, trams, trolleybuses, etc.).

According to the AES study [16], the electricity cost price of a storage power station in 2050 will be 32 ct/kWh or 320 M CHF/TWh (Appendix, Extended report, Table 6.4). As a result, the production savings of the 3 TWh-e also constitute an Annual Financial Savings (EFA) of 1,312 M CHF/year, of which roughly 3/4 by ULISSE (via the TLNs) and 1/4 by “external” CORSAIRE free heating (via the urban DWN):

$$EFA = EEH * 32 \text{ ct/kWh} = 3 \text{ TWh} * 320 \text{ M CHF/TWh} = 960 \quad [\text{M CHF}] \quad (20)$$

Furthermore, according to the AES study [16], the Avoided Investment Cost (AIC) equivalent of two Grand-Dixence Complexes:

$$AIC = 2 \times 2'000 \text{ MW} \times 4,75 \text{ M CHF/MW} = 19 \quad [\text{G CHF}] \quad (21)$$

The potential of ULISSE corroborates the *Position Paper* of May 2022 [41] of the *Forum Energy Storage* Switzerland (FESS), which shows that seasonal heat storage can not only reduce dependence on imported fossil fuels, but can also reduce, in theory, 4 TWh or 40% of the 10 TWh of additional electricity needs in winter (deficit)!

Part B: Environment and lake users' considerations

3.6 Environmental and cohabitation aspects

The environmental issue inevitably arises when we consider "immersing a foreign body" in an aquatic environment such as a lake or even just using its water, for example for energy purposes (thermal impact). This is true even if the intention is “environmentally friendly”.

- Location and dimensions of the under-lake infrastructure
- Type and quantity of materials used
- Direct and indirect interactions with the aquatic environment
- Cohabitations with lake users (navigation, fishing).

3.6.1 Location

The large dimensions of a single ULISSE-type reservoir (2 million m^3 of volume and 54,000 m^2 of projected surface area and footprint on the lake bed), require an ideal water depth of 65 to 75 m for the location. This automatically distances it from the lake bed. This zone, which extends from the shore towards the open sea, forms a gently sloping submerged coastal terrace. In Lake Geneva, it is home to seagrass beds that develop to a depth of around 10 m and are vital to the balance of the entire lake ecosystem [60]. The meadows are already subject to numerous human-induced disturbances to their development, including the destruction of young macrophyte shoots by mooring buoys and boat chains moored in the open water. [56]

3.6.2 Type and quantity of materials used

The ULISSE Reservoir is mainly made up of a semi-rigid/flexible "self-supporting" envelope (with no supporting structure). In addition to stainless steel cables, the shell is made up of a triple layer of type E fibreglass fabric sandwiched between cellular glass thermal insulation blocks. Beads of needled fibreglass or basalt felt are sandwiched between these blocks. The assembly is hydrophobic, inorganic, mineral and inert with respect to the aquatic environment.

The ULISSE Reservoir is anchored by approximately 500 helical screw-in anchors aimed into the lake bed (§ 3.1.2, Figure 8). These anchors are installed in the lake bed from a boat, without a diver or robot, and have virtually no impact on or disturbance of the lake bed (Figure 55 below).

Fig. 55: Impact of a helical anchor aimed at the lake bed (Screw-in Anchor Technology, marinflex.com)

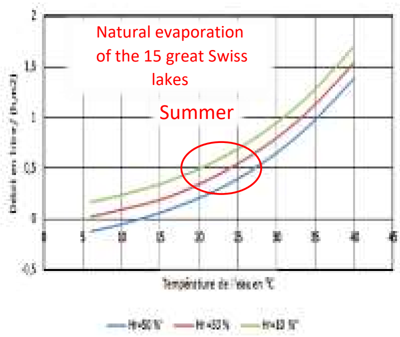
3.6.3 Interaction with the lake

- In the configuration where **the ULISSE Reservoir is charged in summer with the return of tempered water from the TLN network**, the dilution of hot water discharged from the air-conditioning system directly into the lake is avoided, thus reducing the negative impact on the lake, which is already affected by global warming. In particular, global warming tends to modify the seasonal cycle(s) of mixing and thermal stratification of lakes, which influences their deep oxygenation, which is essential for these aquatic ecosystems. [28, 29]

- In the configuration where **the ULISSE Reservoir is charged in summer with temperate water from the upper layers of the lake** (Epilimnion), the selective capture device (phytoplankton filtration) makes it possible to regulate blooms (toxic algal blooms) if necessary and to recover the production of GHGs and CH_4 for energy use in the Reservoir (§ 3.1.3).

- The 621 million m^3 of water confined in the 310 ULISSE Reservoirs constitute 39 PJ of heat and represent a 30 cm thick layer of water spread over the 2,024 km^2 of the 15 large lakes (§ 3.5.1).

Extracting the 39 PJ of heat from the epilimnion lowers the surface temperature of the lakes, **reducing water losses through evaporation by 17 million m^3** (latent heat of vaporisation of water: 2.3 GJ/m^3).



(Image : jcq2.fr/piscine)

Figure 56: Curves of evaporation from a body of water (litre/h.m^2) as a function of water temperature (˚C)

On the other hand, the lowering of the temperature in the epilimnion and on the surface of the lakes increases the solubility or the content of dissolved oxygen (O_2) in the water, which is favourable and essential for aquatic life. In addition, a greater quantity of oxygen is then also transported throughout the lake water column to the bottom by the mixing effect induced by the ULISSE Reservoirs.

- The external thermal convection currents induced by the ULISSE Reservoirs can improve the circulation of nutrients and oxygenation of the water layers at the bottom of the lake, thus protecting the aquatic ecosystem against eutrophication and Global Warming. This thermal convection is illustrated by the numerical simulation of the ULISSE Reservoir carried out at HEPIA (Figure 57 below & Fig. 34 left above).

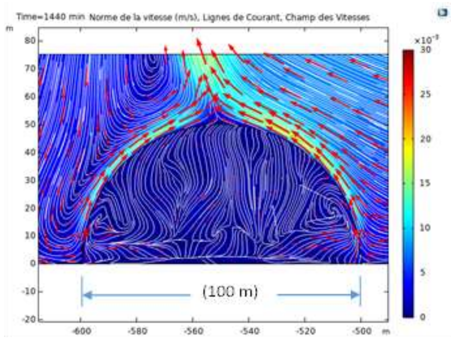


Fig. 57: Thermal convection (water velocity fields) inside and outside the ULISSE Reservoir (cross section of the COMSOL numerical simulation with the modelling of the Reservoir at its true size in the lake)

- The installation of ULISSE Reservoirs in homogeneous areas of the lake can diversify the "ecological niches" and enrich the lake fauna. The area where the Reservoirs are located (protected from fishing) can also constitute a protected area where the fauna can develop peacefully, replenish itself if necessary, and eventually spill over into the rest of the lake, resulting in an increase in the abundance and biomass of fish. This phenomenon is observed in Marine Protected Areas (MPAs). [33, 34]

Extract from the article: ***https://reporterre.net/Les-aires-marines-protegees-le-mirage-de-la-preservation-des-oceans*** [34] *"When there is a marine protected area, all the small fishing boats position themselves around it, because it spreads outwards",* explains Jean-Pierre Gattuso. "*When their levels of protection are high, they are beneficial not only for the ecosystems, but also for tourism, fishing, scuba diving... In most cases, users don't want to part with them",* adds Joachim Claudet...

- Illustrated in Figure 58 below, the ULISSE Reservoir is subject to the internal movements of lake water masses, to varying degrees, which can threaten its structural integrity [61]. Its semi-flexible shell is light and can only deform under the action of water movements. At the very least, under the action of opposing masses of water (horizontal shear), the deformations of the envelope modify the (open) volume of the Reservoir and would cause it to lose some of the tempered water inside. Under no circumstances must the stresses on the Reservoir anchors exceed their holding limits in the lake soil!

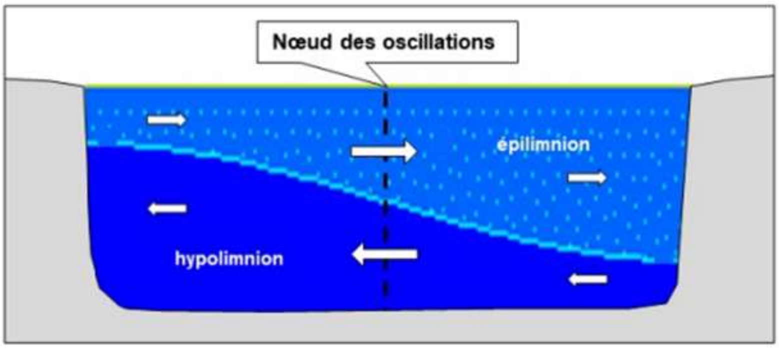


Figure 58: Due to thermal stratification, the currents generated by an episode of seiche and internal seiche oppose each other between the epilimnion and hypolimnion. The strongest currents are created under the oscillation node(s). (Figure extracted from the preliminary analysis report on the risks associated with lake currents threatening the structural integrity of ULISSE, Zsolt Vecsernyes, LHA of HEPIA 2022), Appendix 4. [61]

In conclusion, it is important to study the hydrodynamic and structural stability phenomena of ULISSE in an appropriate way by specialists, in a hydraulics laboratory. The location of the ULISSE Reservoir must be carefully defined. Its size (55 m high, 100 m wide, 560 m long) could have an impact on lake currents, especially if several units are installed in parallel. The reduction of the wetted section of the lake increases the speed of the current, at least in the vicinity of ULISSE. These aspects should be the subject of hydrodynamic analyses by a specialist. [61]

3.6.4 Co-existence with lake users (navigation, fishing)

- **Navigation**: Anchored to the lake bed, the top of the ULISSE Reservoir is located approximately 10 to 15 m below the surface of the lake. It is therefore invisible from the surface and will not interfere with navigation. The water catchment device in the epilimnion zone, if used, does not come closer than 3 m below the surface. It is lifted out of the water only in the presence of a specialised maintenance boat, which is duly marked. For example, the draught of the large CGN (Compagnie Générale de Navigation) boats on Lake Geneva is less than 2 m. Pleasure boats (sailboats) have a keel draught of barely 1.2 m.

- **Fishing**: Fishing is probably the lake activity that can be most influenced/impacted by the presence of ULISSE Reservoirs [60]. However, this interference can be put into perspective, given the respective surface areas and lake volumes involved.

- The potential installation of 310 ULISSE Reservoirs would total 17 km^2 of (invisible) right of way on the lake bed, which represents 0.8% of the 2024 km^2 of the total surface area of the 15 large lakes (> 10 km^2), of which 1,233 km^2 are on Swiss territory (61%). For Lake Geneva, the potential of **87 ULISSE Reservoirs also represented the equivalent of 0.8% of the surface area and 0.2% of the volume of lake fishing.**

- The 580 km^2 of surface area and 167 km of shoreline of Lake Geneva are shared between 150 professional fishermen (with still nets and fish traps) and around 8,000 amateur fishermen (with lines and trolls), catching around 1,000 tonnes/year of fish (≈ 10% by amateur fishermen). Source: **http://leurres.ch/leman.html**. Amateur fishermen use lines and trolls, generally towed by a boat in motion or anchored in the lake. These lines, which can be up to a hundred metres long, are fitted with hooks that can potentially interfere with or even catch on the casing of the ULISSE Reservoir.

- In the same way as for professional fishing gear set or stretched in the water and anchored, **ULISSE Reservoirs can, in addition to being clearly mapped and geolocated, be marked with physical markers to help anglers avoid them.** The installation of ULISSE Reservoirs in large lakes should be carried out in consultation with anglers and by demonstrating their positive environmental impact.

Part C: Economic considerations

3.7 Estimation of financial investment cost of the ULISSE Reservoirs

3.7.1 Comparison with large hydrothermal storage systems

At the stage of this exploratory study of the ULISSE project, it is difficult to establish the financial investment required for the construction of a completely new Reservoir, and what is more of several entire networks with almost 300 ULISSE Reservoirs potentially installed in the 15 large Swiss lakes. At best, on the basis of the dimensions of the typical Reservoir and the inventory of the main constituent materials, an order of magnitude can be given for the Material cost, but it is more difficult to give an order of magnitude for the cost of manufacture and installation on site (lake bed).

The cost of the in-depth multi-disciplinary study phase and of producing a pilot prototype is also premature to establish in the present exploratory study. Nevertheless, an analysis of the biggest projects in the field of solar heat storage gives an initial idea of the financial investment potentially required.

The graph in Figure 57 below shows a broad distribution (factor 100) of the cost (CHF/m^3) according to the type of storage (*Tank, Pit, Borehole, Aquifer*) and according to the "water equivalent" volume. Each type of storage has its own range of effective implementation sizes. Pit storage covers the entire range.

Buried/covered basins and *pit and boreholes* cover a wider range in terms of the number of projects and the volume/cost ratio (700 m^3, 500 CHF/m^3 and 200,000 m^3 @ 24 CHF/m^3 for the largest storage facility at Vojens in Denmark).

Generally speaking, Graph 59 below shows that the various heat storage systems are distributed globally along a diagonal by linear regression (logarithmic abscissa). This shows a downward trend (cost by volume vs size) towards the bottom right-hand corner of the graph (10 CHF/m^3 for 10^6 m^3). Such a hydraulic sensible heat storage system of 2 M m^3 water equivalent would represent a unit investment cost of around 20 M CHF (equivalent to the ULISSE type Reservoir).

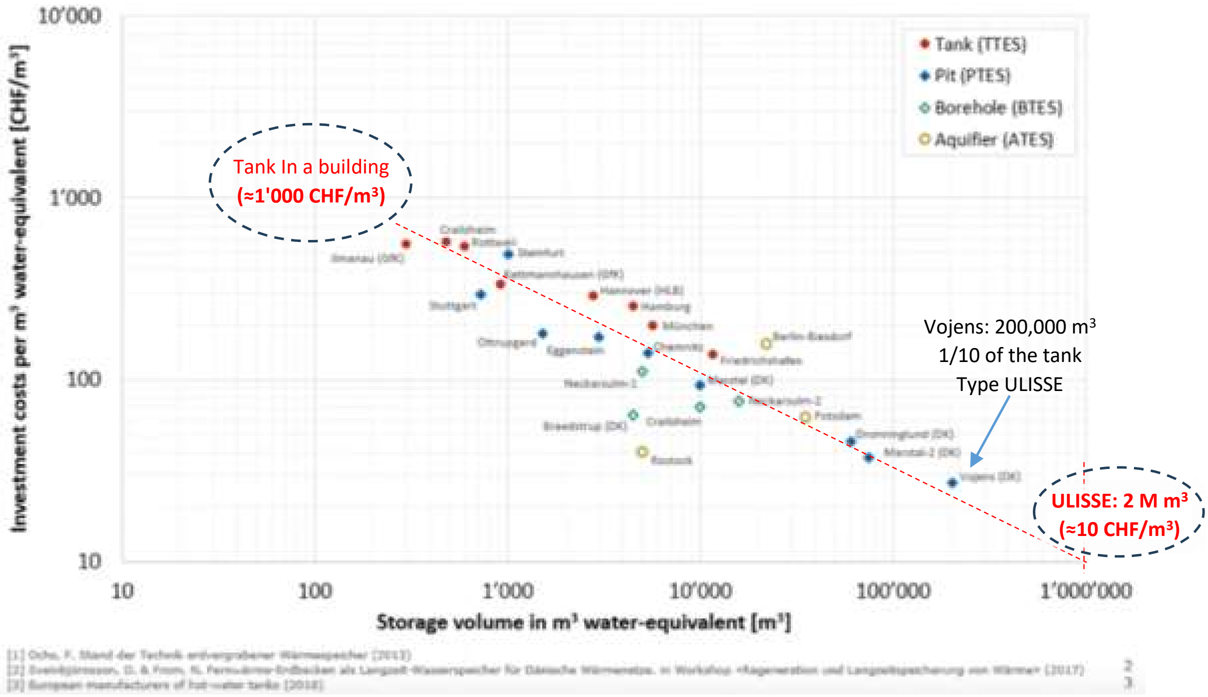


Figure 59: Investment costs for different types of hot water storage (source: HSLU Hochschule Luzern). The effect of size (economy of scale) can be seen with a linear regression tending towards 10 CHF/m^3 @1 M m^3

3.7.2 Land area for the solar collectors and the thermal storage basin

Seasonal storage systems are generally combined with a field of solar thermal collectors and a heat distribution network with heat pumps connected to the buildings. These solar thermal collector fields also require a significant amount of land (including the purchase and use of land).

For example, illustrated in Figure 60 below, the largest heat storage system in the world using solar thermal collectors for district heating is in the Vojens conurbation (DK). It covers a surface area of 144,000 m² or five (5) times that of his seasonal heat storage reservoir alone (27,000 m²)!

Figure 60: Fields of solar thermal collectors for district heating in Vojens, Denmark, (70,000 m²) next to the seasonal storage tank (210,000 m³) under construction in 2014-15 (still without the insulating and floating cover). (source: http://solarheateurope.eu/2020/05/19/vojens-district-heating/)

Illustrated in Figure 61 below, in comparison, the projected footprint on the lake bottom per unit of stored energy (m²/TJ) of a ULISSE Reservoir is therefore almost eight times (7.6) less than the largest seasonal storage system on land (Vojens).

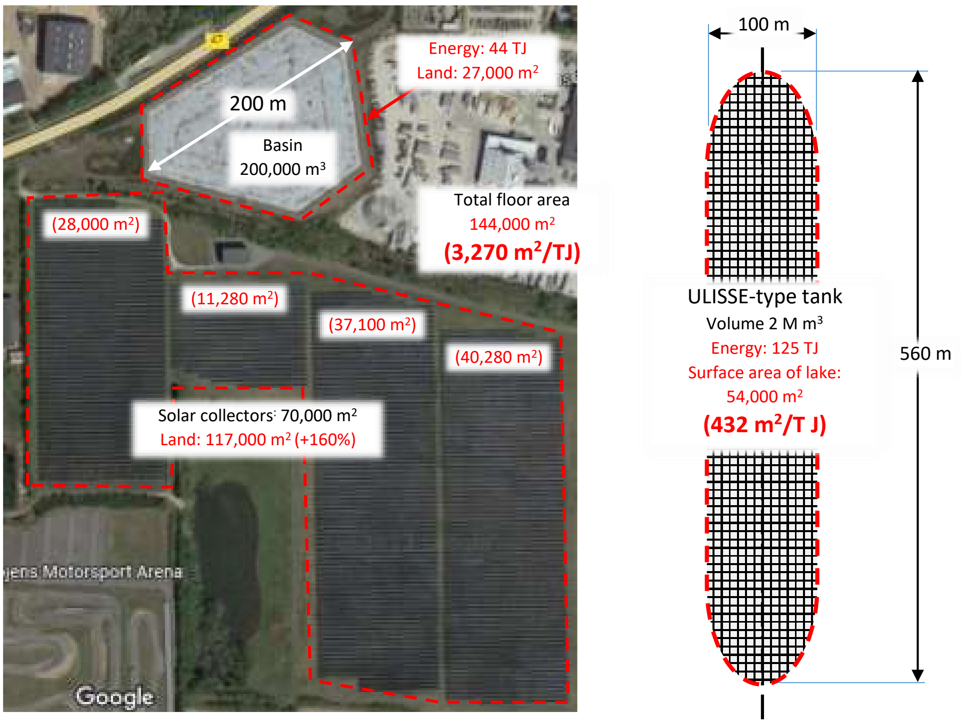


Figure 61: Total footprint: 144,000 m² (land) for solar thermal collection infrastructure (70,000 m² of flat collectors) and the seasonal storage basin (210,000 m³ with its floating cover) of the urban agglomeration of Vosjens fjernvarme (DK) and comparison with a ULISSE Reservoir.

The energy density (MJ/m³) of ULISSE is admittedly lower (1/3) because it operates with a lower thermal excursion (ΔT full-empty = 15 K for ULISSE compared with 50 K for the Vojens basin). However, the ULISSE system does not need any land to capture the solar heat energy, as it draws it directly from the lake, or is charged by industrial or air-conditioning waste heat (=> TLNs).

The financial cost of solar thermal collection can therefore be three times that of the storage system alone. For example, at Dronninglund (DK), the 62,000 m³ covered storage basin cost ≈ 2.4 M € and the 37,000 m² solar thermal collector cost 6.1 M € in 2014 (165 €/m²)! However, it is not specified whether these costs include the price of the land (one might logically assume that they do).

The (invisible) lake footprint of ULISSE is 13 % of a (terrestrial) field of solar collectors and storage basin.

Note: Although "terrestrial solar" heating systems such as Vojens and Dronninglund require less energy from the heat pumps (2.5 to 3 kWh/MWh solar for Dronninglund) at higher temperatures from the district heating network, they cannot be used for air conditioning, particularly free cooling like the TLNs.

3.7.3 Summary comparison of ULISSE with alternative solutions

TLN network infrastructure is not taken into account here, as it is planned as part of the general development (Switzerland, SES-2050) of heat networks, including those on lakes.

ULISSE alone (without external CORSAIRE) Implementation in 2050 in the 15 major Swiss lakes:

- ⇨ Heat input via TLNs: Qh = 50 PJ/year (1/4 of the Swiss "lake" population = 50 GeniLac units: ≈ 1PJ).
- ⇨ Net winter electricity savings (EEH): 2.07 TWh
- ⇨ Financial cost Prototype reservoir including ULISSE study (2 M m³): CHF 20 M (subject to confirmation)
- ⇨ **Cost 310 Reservoirs (621 M m³): 3 billion CHF (≈ 50 % economy of scale vs. prototype).**

CORSAIRE contribution (via DWN and external to TLN)

- ⇨ Heat input (Q-cor): 6.75 PJ
- ⇨ Net winter electricity savings (ΔEcor): 0.69 TWh
- ⇨ **Cost of interconnection networks and heat exchangers: CHF 1 billion (assumption).**

Total (ULISSE & CORSAIRE)

- ⇨ Net electricity savings (EEHn): 2.76 TWh
- ⇨ Gross electricity savings (EEHb) (10% distribution losses in winter): 3 TWh
- ⇨ Accounts for 1/3 of the structural winter electricity deficit (9 TWh)
- ⇨ **Financial cost of ULISSE + CORSAIRE infrastructure: CHF 4 billion**
- ⇨ **Financial savings on electricity (320 M CHF/TWh): 960 M CHF/year [16].**

Alternative through additional electricity generation:

1. Gross electricity production equivalent to 2 Grande Dixence (GD) complexes: 3 TWh winter
- ⇨ **Capital cost of 2 GD Complexes ≈ 19 billion CHF (based on Table 6.4, cost of Large Hydro).**

Alternative by supplying thermal networks:

2. TLNs with solar thermal collectors and onshore seasonal storage: ≈ 57 PJ => § 7.6 (extrapolation from the Vojens, DK installation)
- ⇨ Surface of solar thermal collectors and associated land (160%): 35 km² & 56 km ²
- ⇨ Volume of seasonal thermal storage (≈ 85˚C) and surface area: 26 M m³ & 35 km²
- ⇨ Total surface area (collectors + storage): 91 km² (≈ the surface area of Lake Zurich)
- ⇨ Investment cost of solar collector field (excluding cost of land): ≈ 5800 M CHF
- ⇨ Investment cost of thermal storage (excluding land cost): ≈ 780 M CHF
- ⇨ **Total investment (collectors + storage): CHF 6580 million (excluding land purchase).**

3.8 Overall discussion

ULISSE aims to optimize (boost) the hydrothermal potential of the great Swiss lakes while protecting them. This by improving the energy efficiency for the heating by heat pumps and the free cooling air conditioning as well as associated with CORSAIRE free heating to reduce the negative energy impact of the winter drop in the temperature of the public drinking water network (i.e., two ways of capture, storage and recovery of thermal solar energy as well as heat rejection).

The ULISSE system first of all provides a winter thermo-lacustrine source of about 20°C, higher than that of ordinary at 5-6°C, which will double the efficiency of heat pumps (HP) and reduce 95% of the energy for pumping and circulating the water in the said TLN networks.

This ULISSE heat source consists of large "tunnel" reservoirs, anchored on the lake bottoms, with a unit storage volume of 2 million m^3 and a thermal capacity of 125 TJ each. These ULISSE Reservoirs are charged in summer with temperate water, either from the upper layer of the lake (Epilimnion) heated by the sun, or by discharges of industrial heat and air conditioning. The loading pumps are powered by photovoltaic electricity absorbing the summer production peaks of the photovoltaic installations and avoids the use of their so-called peak-shavings.

The second way of using the temperate water supplied by the ULISSE Reservoirs or other thermal discharges is to correct (5 to 10˚C) the winter drop in temperature of the public Drinking Water Networks (DWN) by the CORSAIRE free heating (without heat pump). All DWNs are potentially affected by “free heating” which can provide 30% of the heat for Domestic Hot Water (DHW), reduce the electricity consumption of washing machines/dishwashers connected to the DHW and increase the electrical efficiency of TLNs. [42 to 52]

Significance for implementing Switzerland’s Energy Strategy 2050 and achieving the country’s climate goals

The ULISSE system, in combination with the CORSAIRE free heating, has been proposed as a support of the Confederation's Energy Strategy 2050. The ULISSE project, with approximately 300 Reservoirs distributed invisibly in the 15 largest Swiss lakes and in association with CORSAIRE free heating (including outside lake regions), could provide nearly 60 PJ or 30% of the 200 PJ of needs national energy-heat systems for room heating and DHW. **This would save 3 TWh of gross electricity in the winter semester (1/3 of the 9 TWh national winter electricity deficit,** equivalent of twice the winter production of the Grande Dixence hydroelectric complex (1,5 TWh).

4 Cooperation and coordination with SWEET consortia and SOUR projects

There have been some exchanges, but no cooperation with the SOUR BILS project. BILS also explored a concept of large thermal storage in lake, but with a totally different approach than ULISSE, since it investigated the possibility to store in a lake in a plastic reservoir very hot water (around 90˚C) produced by a classic thermal solar collector field.

There were also some contacts and ongoing discussion with the SWEET DeCarbCH consortium. **ULISSE is effectively close to the objectives of DeCarbCH**, particularly concerning the efficiency of heat pumps and the development of heating networks. A synergy or collaboration would certainly be interesting. Following initial constructive discussions, the ULISSE project will be presented to the internal and external partners of the DeCarbCH consortium.

5 Outlook and next steps

The ULISSE project, in conjunction with the CORSAIRE free heating system, is in line with Switzerland's energy strategy 2050. It could enable the development of thermal networks and seasonal heat storage, reducing the structural winter electricity deficit, as encouraged by the *aeesuisse* Swiss Energy Storage Forum (FESS). [41] There is also significant international potential for ULISSE & CORSAIRE, where there are large lakes (specifically for the ULISSE booster of the Thermal Lacustrine Networks) and even outside lake regions (CORSAIRE free heating of the public Drinking Water Networks).

The ULISSE project could be advantageously pursued, along the following two lines:

A. For the ULISSE part:

1. Continuing the numerical simulation (COMSOL) of the Mock-up and the full-scale simulation of the Reservoir.
2. Analysing the potential for installing ULISSE Reservoirs (2 M m^3) in the 15 major Swiss lakes.
3. Carry out an in-depth environmental impact assessment for the lakes concerned.
4. Carrying out an in-depth study of the hydrodynamic behavior of the Reservoirs in relation to lake currents; in particular, the structural integrity of the Reservoirs in relation to the internal seiches causing adverse internal shear currents in large lakes (Appendix: 3).
5. Development of an autonomous drone for cleaning the shell and inspecting the standard Reservoir.
6. Development of a first prototype of the Intermediate Reservoir for an initial behavior study in a closed basin or lake.
7. Production and installation in a real situation of a test pilot of typical size (2 M m^3) with observation of the physical and environmental behavior in relation to the receiving lake. Proposal

Proposition

The ULISSE Pilot Reservoir could advantageously be installed in Lake Geneva opposite EPFL and UNIL and connected to the new Pumping Station (SPP) on both campuses, for cooling and heating with lake water and the new heat pumps (HP) located in the EPFL thermal power station (CCT)!

Illustrated in Figure 62 below, the ULISSE Pilot Reservoir could be located near the EPFL-UNIL suction strainer, which is only 900 m from the shore where the SPP is located and 75 m deep (ideal for a typical

ULISSE Reservoir). Its connection to the CCT would make it possible to test the energy impact on the performance of the heat pumps.

Figures 62: Proposed installation in Lake Geneva and connection of the ULISSE pilot to the heating and cooling infrastructure (SPP + CCT) at EPFL-UNIL, with environmental and physical observation by the LéXPLORE platform.

One of the objectives of the ULISSE exploratory study project was to study its impact on the heating system (100% thermo-lacustrine since 2022) of EPFL (main site of Ecublens) as well as that of UNIL in 2025. [59] The EPFL-Ecublens heating system is mainly renovated at the level of the Pierrettes Pumping Station (PPS), the Thermal Power Plant (CCT, *Centrale de Chauffage Thermique*) with 4 new Heat Pumps (HP), totaling 24 MW of thermal power and to which is added 4 MW from the data-center placed above the CCT. [58]

Based on EPFL's Energy Master Plan 2015-2045, in 2014 the Ecublens site's heating requirement was 34 GWh. Nearly 70% (24 GWh) of the heat was extracted from Lake Geneva, with the remaining 30% supplied by heat recovery from the oil-fired turbines. By 2045, the heating needs of the EPFL's Ecublens site will have risen to 50 GWh-t/year (up 50% on 2014), supplied since 2022 by water from Lake Geneva and 4 new heat pumps. With a predicted annual COP of 5.5 for the heat pumps, their electricity consumption should reach almost 10 GWh to extract 40 GWh thermal/year from Lake Geneva and supply them at a maximum of 67˚C to the heating network.

Illustrated in Figure 63 below, UNIL also plans to switch entirely to heating its buildings using the same lake system as EPFL by 2025. For all the EPFL + UNIL + Vortex heating, lake water requirements in 2030 and 2050 will be 1.7 and 2.35 m^3/s respectively, compared with the 2.5 m^3/s capacity of the new Pierrettes Pumping Station (SPP).

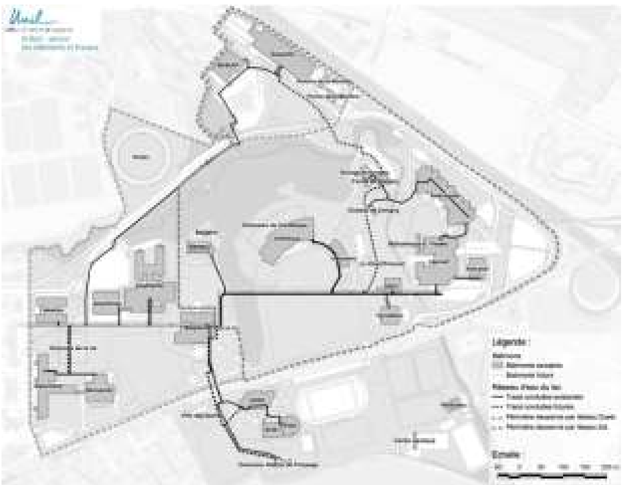


Figure 63: Map of the Dorigny campus, with the pipes to be added as part of the project to extend the pumping station and adapt the network dotted in black (source: Canton de Vaud, EXPOSE DES MOTIFS ET PROJET DE DECRET - pour financer l'agrandissement de la station de pompage et l'adaptation du réseau de distribution d'eau du lac alimentant le Campus de Dorigny, July 2019).

With these lake water flows and an identical heat pump COP (5.5) for EPFL and UNIL, the thermal energy for heating the two universities could reach 60 GWh-t @ 1.7 m^3/s in 2030 and 80 GWh-t @ 2.35 m^3/s in 2050. Electricity consumption by the heat pumps will also reach 11 and 15 GWh respectively.

To this must be added that of the SPP's primary circulation pumps, for the increase in the mass of water pumped: 0.8 GWh for 14 M m^3 in 2030 and 1 GWh for 19 M m^3 in 2050, as well as the pressure losses in the hydraulic network between the water suction strainers, the evaporator of the heat pumps and up to the point of discharge into the Sorge River.

Main thermal parameters EPFL-UNIL without and with ULISSE:

- Temperature (winter) cold spring of Lake Geneva (Tf): 5 to 6 °C
- Temperature (winter) source ULISSE (Tu): 18 to 20 °C
- Water discharge temperature at the heat pump evaporator outlet (Tr): 2 to 4°C
- Temperature difference on the evaporator of ULISSE heat pumps (without) (ΔTf-r): 3 K
- Temperature difference on the evaporator of ULISSE heat pumps (with) (ΔTu-r): 15 K
- Maximum water distribution temperature at heat pump outlet (heating network): 67 ˚C

As a first approximation, based on the ULISSE impact study on GeniLac (§ 5), which indicates a potential gain of 50% on the COPsys, the heating system for the EPFL + UNIL + Vortex campuses could benefit from a 50% reduction (6 to 8 GWh/year) in electricity consumption (SPP + CCT), to supply 60 to 80 GWh heat (2030/2050). This would have a fivefold positive energy impact:

- Reducing (by a factor of 5 or -80%) the volume/mass and therefore the flow of water to extract the heat required for EPFL's heating needs from the lake,
- 95% reduction in pressure losses (proportional to the square of the flow rate) and the corresponding energy required to pump lake water through the heat pump evaporators,
- Reduction (-80%) in the potential energy of the water mass rising from the lake,
- Increase (+50%) in the Coefficient of Performance (COP) of heat pumps, or reduction in the corresponding electrical energy absorbed,
- Reduction in demand and heat losses for drinking water consumption during the heating season using CORSAIRE free heating: 125 to 175,000 m^3 @ ΔTep ≈ 10 K, => free-heating supply (without heat pump) = 1.5 - 2 GWh (2030-2050).

Physical and Environmental observation of the ULISSE Pilot Reservoir

Physical observations of the ULISSE Reservoir and its environmental impact could be advantageously carried out using the LéXPLORE research platform. Since 2018, the LéXPLORE platform has been anchored for 8 years (110 m deep, 570 m from the shore) on Lake Geneva opposite the port of Pully (VD), 6 km from the Lausanne campus (Figure 64 below).

Photo https://lexplore.info/fr

Figure 64: LéXPLORE platform for lake research on Lake Geneva, currently anchored opposite the port of Pully (VD)

B. For the CORSAIRE free heating part:

The ULISSE project, associated with the integration of the CORSAIRE free heating process, could restart the CORSAIRE project officially included and initiated in Cantonal Energy Master Plan 2001-2005 of Geneva. [46]

The *Services Industriels de Genève* (SIG) are in charge of the public Drinking Water Network (DWN) of the canton of Geneva and fully involved in the GeniLac project, “Flagship” of the TLN in Switzerland. For this, the following points could be taken up:

- The basic study (master thesis of W. van Sprolant EPFL 1995).
- The study of the specific heat loss of the Public Drinking Water Network (DWN).
- The study of the physical integrity of the DWN (under winter free heating).
- Study of the sanitary integrity of the tap water undergoing a winter temperature correction.
- Psychosociological study of the acceptance of the winter modification of the tap water temperature
- Study of the impact(s) of the CORSAIRE free heating on a pilot building.

Proposition

To effectively carry out a multidisciplinary impact study of the CORSAIRE free heating on a building stock representative of an urban agglomeration, it is necessary to choose a large set of buildings, at least equivalent to a district of housing and with various shops.

To simultaneously test the heat transfer from the source of thermal waste to the DWN, it would be useful for it to be close to the buildings concerned. This also makes it more practical to conduct multidisciplinary studies within a limited perimeter. Illustrated in Figure 65 below, the *Cité du Lignon*, with 2,780 housing units, 7,000 inhabitants, various shops and a few hundred meters from the Wastewater Treatment Plant (WTP) Aïre, could be an ideal candidate for a pilot.

Figure 65: The Cité du Lignon "the longest building in Europe" (1 km)

The WTP Aïre, with its 140,000 m^3/day and 2 m^3/s flow, is the main wastewater treatment plant in Geneva and Switzerland. After the treatment, its water from the fully covered basins has still a temperature higher than that of the public drinking water network in winter (DWN). The waste heat can be transferred by free heating using a heat exchanger. [65] The distance from Aïre's WTP is only a few hundred meters from the DWN loop which supplies the *Cité du Lignon* (Figure 66 below).

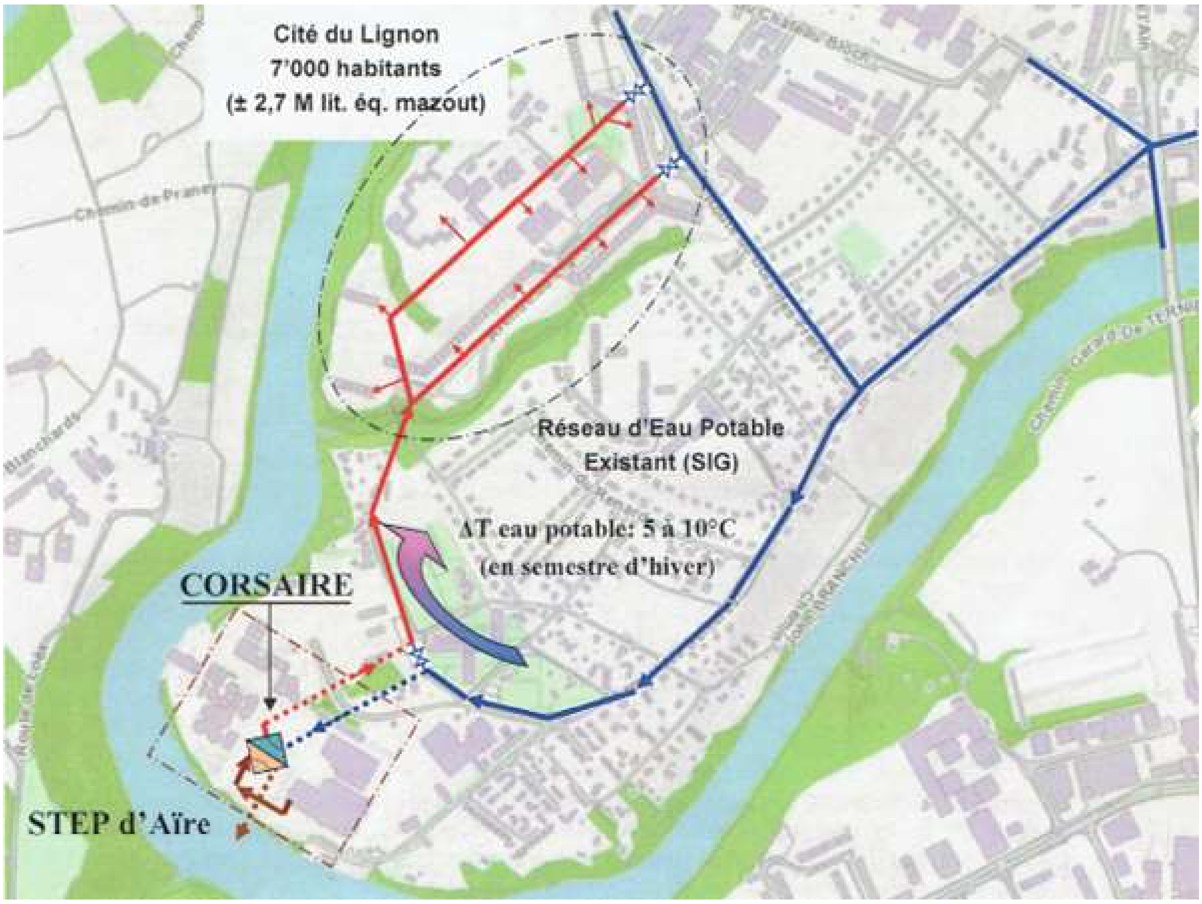


Figure 66: Proposal for the Cité du Lignon in Geneva connected to the Aïre WTP as Pilot for the multidisciplinary study of the impact of CORSAIRE free heating

6 Outputs and outreach

Public oral and visual presentations (scientific or broad audience)

Members and coop. partners	**Description:** author(s), title, name of the event and location, year of presentation
W.van Sprolant et al.	Simulation of an Under Lake Infrastructure for capture and Storage of Solar Energy (ULISSE), COMSOL Conference Munich 2023 **Best Poster Award by popular vote**!

Patent applications and awarded patents

Project partner	**Description:** inventor(s), title, priority date, patent exploited, status, validity, brief description
W.van Sprolant	Patent Application CH000205/2022 du 1st Mars 2022 : "*Dispositif combine de captage mobile de stockage d'eau tempérée et de méthanisation subaquatique*".

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Appendices

- French extended version of the ULISSE project report
- English translation of the extended version of the ULISSE project report (translated with DeepL)