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| <b>Institution:</b> Ulster University  |
| <b>Unit of Assessment:</b> 13: Architecture, Built Environment and Planning  |
| <p><b>1. Unit context and structure, research and impact strategy</b></p> <p><b>a. Context and Mission</b></p> <p>Research in Architecture, Built Environment and Planning is carried out within the Belfast School of Architecture and the Built Environment (BSABE), one of four schools comprising the Faculty of Computing, Engineering and the Built Environment. The unit successfully integrates a range of engineering solutions and technologies to inform policy, investment and development decision making. Sustainability and enhancement of the quality of the built environment for societal well-being provides a common underpinning to our research agenda through the evaluation of societal and environmental challenges of global significance. Our extensive international partnerships provide recognition for our scientific expertise and are influencing global research agendas. A critical mass for the unit is achieved via a strong nucleus of research staff, a vibrant PhD community, a solid track record of national and international research funding and impact through engagement with stakeholders in industry, professional practice and government bodies. Our activities cover a wide range of research areas including sustainable design, retrofitting building technologies, alternative energy sources, net-zero carbon building, fire safety of buildings and materials, safety of hydrogen and fuel cell technologies, resilience of infrastructure, urban regeneration, housing and real estate, future well-being of urban environment and digital construction.</p> <p>In REF2014, <b>100%</b> of our research environment and impact were judged to be world-leading and internationally excellent. We have built on this excellence within the reporting period to be a leading internationally focused research unit delivering our research towards the creation of a more sustainable and resilient built environment with improved health and livelihoods. To achieve this our mission is to:</p> <ul style="list-style-type: none"> <li>• <i>apply</i> our research for solutions to real-world problems associated with built environment,</li> <li>• <i>ensure</i> a supportive and intellectually challenging research culture,</li> <li>• <i>support</i> strong infrastructure for interdisciplinary research,</li> <li>• <i>deliver</i> research with global impact,</li> <li>• <i>facilitate</i> multidisciplinary interactions and collaborative research environment, and</li> <li>• <i>maximise</i> the benefits of our research to the scholarly community.</li> </ul> <p><b>b. Structure and Research Management</b></p> <p>The unit constitutes of <b>four</b> established Research Centres and <b>two new</b> Research Groups formed within this REF cycle and have over 145 research active staff (Academics, Contract Research Staff (CRS) and Post Graduate Researchers (PGR)) spanning across all disciplines within Built Environment:</p> <p><b>Research Centres</b></p> <p><b>Centre for Sustainable Technologies (CST) (Director: Hewitt; 12 FTE)</b> – delivers decarbonisation solutions for energy supplies and their energy efficient use within the built environment through technology development informed by economic and social analysis.</p> <p><b>Research on Property and Planning (RPP) (Director: Haran; 16.5 FTE)</b> – provides innovative insight and objective research to support sustainable urban and rural development, tackle climate change while simultaneously working in partnership with policy makers and industry to address social exclusion, deprivation, and deficiencies in housing provision.</p> |

**Hydrogen Safety Engineering and Research (HySAFER)** (*Director: Molkov; 5 FTE*) – leads hydrogen safety and fuel cell research and education globally to underpin the international standing of Ulster University.

**Fire Safety Engineering Research and Technology (FireSERT)** (*Director: Nadjai; 7.8 FTE*) – enhances the public safety and the competitiveness of UK industry through development of fire safe materials and products, performance prediction methods and measurement technologies.

### Research Groups

**Studies Allied to Built Environment Research (SABER)** (*Director: Woodward; 7 FTE*) – This Research Group represents the collative interests of an emerging research culture within the unit spanning the core subject areas of highway engineering, construction management, quantity surveying, building surveying and civil engineering. SABER was established in late 2014 specifically to raise the underpinning research base in these subjects and delivers applied research solutions and technology development in collaboration with the built environment.

**Architecture Research Group (ARG)** (*Director: Houlihan Wiberg; 4.5 FTE*) – The merger between the previous Belfast School of Architecture and the School of the Built Environment in 2017, has created an opportunity to deliver interdisciplinary research by combining the architecture discipline with sustainable technologies, construction and planning. Established in 2020, ARG consists of four research clusters: (i) Zero Emission Buildings and Communities; (ii) Hidden Barriers and Divisive Architecture; (iii) Drawing: methodology, making and media; and (iv) Practise Based Research. The vision is to develop an international, interdisciplinary, innovative research portfolio to design appropriate concepts and strategies for net zero emission buildings and communities, with strong interests in the health and well-being of the people.

The unit's research is led by the Research Director (RD) (**Mondol**) who is an integral part of the School Leadership Team. Each Research Centre and Research Group is led by a Director (RCD/RGD), who is responsible for implementing the associated research strategy. Our School Research and Impact (R&I) committee is chaired by the RD and the members include RCD/RGD, Head of School (**Hewitt**) and Post Graduate Tutor (**Davison**). The committee meets 6 times per year to oversee all research activities including setting up the R&I strategic goals for the unit, maintaining operational excellence, devising the strategic plan for the training and support of academic staff and researchers and formulating ideas for the development of interdisciplinary and multidisciplinary research projects. The RD works closely with the faculty's Associate Dean for Research & Impact to support the strategic direction of the faculty research, to promote interdisciplinary research and to achieve impacts. Coherency of purpose arises from complementarities and supportive management structures within the Faculty and School.

Research in UoA13 maintains the highest standards of professionalism in research as set down by the University (See **REF5a**). All research projects that need ethical approval are managed by the Faculty **Research Ethics Committee** which comprises discipline specific experts drawn from each school within the Faculty. **100%** of our research active staff members have completed the online Research Integrity Training course. New CRSs take this course as part of their induction activity and PGRs during their first year of the research programme.

### c. Research Strategy and Outcomes

In our REF2014 submission it was stated that our research strategy going forward to the current exercise would be influenced by the global, national and local economic conditions, public policy, government expenditure, societal needs and mitigation of climate change via sustainable development. The key objectives in regard were to

- *design* new technological solutions and standards for societal well-being,
- *develop* research in renewable energy and energy efficient technologies,
- *deliver* policy relevant research,

- *increase* collaborative research in partnerships with industries and commerce, private sector, government bodies and local stakeholders,
- *expand* our research network and collaboration,
- *disseminate* research output to wider communities,
- *evaluate* impact via demonstration,
- *exploit* technologies into commercially viable products, and
- deliver research informed courses and trainings.

Over the assessment period, we have successfully achieved all these objectives as evidenced through the following key indicators:

- **Growth of Research Active Staff:** increased the number of staff returned in this submission from a headcount of **40 in REF2014 to 55 in REF2021** (see **Section 2a**) clearly indicating our active engagement in research and the positive outcomes from our mechanisms for staff supports.
- **Increased the PGR Completion Rate:** a total of **74** PhDs were awarded, **20%** higher than REF2014. Importantly, our collaborations with external organisations have facilitated growth in PGR numbers through exploiting alternative funding sources (see **Section 2c**).
- **Increased Research Spend:** higher levels of success for **Research Council (RC)** income (**£6.8M**) coupled with diversified external research funding base has seen the total new research spend over the assessment period to reach **£22.9M**, an increase of **74%** compared to REF2014 (see **Section 3a**).
- **Research Networking and Collaboration:** extensive engagement with partners regionally, nationally and internationally is evidenced (see **Section 4b,c**) by an increase in research income from EU Government bodies and other EU sources, **118%** higher than REF2014 values (see **Section 3a**).
- **Engagement with Industries, Commerce and Private Bodies:** enhanced our engagement with these communities locally and nationally and have delivered 8 Invest Northern Ireland Centre for Advanced Sustainable Energy (NI CASE) projects, **3** KTPs and **3** Innovate UK funded projects in partnerships with industries and commerce (see **Sections 3a and 4a,b**)
- **Commercial Exploitation:** commercial potential of the research project has been exploited through **4** Invest NI Proof of Concept (PoC) funding awards, **12** patent applications and **24** invention disclosures.
- **Contribution to the Local Economy:** delivered more than **50** innovation voucher projects funded through Invest NI and Enterprise Ireland to support industries in developing their products, processes, and services.
- **Dissemination:** published over **465** peer reviewed journal articles, **225** conference papers, **58** research reports for government bodies and industries and contributed **60** books/book chapters within this REF period.
- **Support New Research Areas:** established two new Research Groups (**SABER** and **ARG**) with the expectation that they will evolve into Research Centre signifying our strategic initiatives to develop disciplinary research.
- **New Research Informed Courses:** introduced a new MSc programme in **Energy Storage** and a PgCert programme in **Hydrogen Safety** that directly originated from our research contributions.

A summary of key research activities within each Research Centre within this REF period is provided below:

**CST:** CST's research has continued to focus on the development, integration and assessment of decarbonisation allied to future energy scenarios and renewable energy technologies, a strategic priority research area identified in REF2014. CST has secured over **£14.7M** new grant income in the areas of heat pump, energy storage, heat distribution network, solar technologies, clean coal and carbon capture and efficient building components (see **Section 3a**). Building upon a previous

EU funded project (**SPIRE**), the group has secured **£2.3M** INTERREG funding for stage 2 of the project (**SPIRE 2**). A cross-border SFI-DfE funding award (**£633K**) has allowed researchers to investigate the impact of wind generation penetration and the deployment of large-scale energy storage system on Ireland's electricity market. New areas of research have also emerged within this REF period funded via **H2020**, for example, the research on the urban wastewater management to address the future challenges arising from climate change (in **ALICE**, **£104K**); investigation on healthy environment and suitable urban solutions for an aging society (in **GRAGE**, **£66K**); and feasibility study on application of renewable energy and energy efficient solutions into buildings and public infrastructure (in **CLARA**, **£131K**).

**HySAFER**: The Centre has extended their fundamental and industry-driven research to engage with breakthrough safety strategies in hydrogen and fuel cell (**HFC**) technologies and has attracted over **£4.3M** in new research projects in this REF period. Key research outcomes include the invention of explosion free in a fire TPRD-less hydrogen storage tank, CFD modelling of hydrogen tank under a vehicle in a tunnel, development of fire test protocol for UN Global Technical Regulation No. 13 and quantitative risk assessment of hydrogen onboard storage. Within the UK, HySAFER has made valuable contributions in two EPSRC **CDT** projects in 'Fuel Cells and Their Fuel' and 'Sustainable Hydrogen (SusHy)' by training a new generation of scientists/engineers for the emerging hydrogen economy and to champion hydrogen safety research in the UK through EPSRC SUPERGEN H2FC hub.

**RPP**: The Centre has a longstanding and critically acclaimed international research portfolio across the inter-related spectrum of the built environment, including property and real estate research, housing, regeneration, planning, sustainability, urban development, facilities management and infrastructure investment and development. The team has secured circa **£4.2M** in new research funding. RPP continues to produce sector leading quarterly reports on the '**NI House Price Index**' providing valuable information on the private housing sector and utilised extensively by policy makers and industry bodies to inform new product innovation and perform viability assessments. RPP has initiated a new research strand in Marine Spatial Planning (MSP) and has also established a growing global reputation in the areas of energy efficiency of buildings and the decarbonisation of the built environment.

**FireSERT**: Success in attaining **£1.5M** of new research funding within this REF cycle has allowed researchers to continue research on blast and fire protection system; integration of fire safety mechanism within buildings; investigation of localised and travelling fire in compartments; development of CFD codes for fire dynamics and preparation of training materials on fire safety. Several smaller, but equally important projects have involved working with Essexford Joinery Ltd to improve the fire resistance of timber doors; assessment of sprinkler performance under fire for Marks & Spencer; investigation on flash over and smoke movement for Longboat Quay Development in Dublin. In 2017, a new joint venture between FireSERT and the **Efectis Group**, a sector leading international fire testing and engineering company has facilitated research in the commercial arena resulting in **£475K** in consultancy income within this REF period.

#### d. Future Research Strategy

With the exponential development in the field of Data and Information Science (e.g. the advent of big data and the rise of cloud-based computing and remote sensing), industries operating in the built environment are experiencing a transition to new revolutionary paradigms for the design and management of Buildings and Infrastructure systems. Hence, central to our research strategy over the next five years is a focus on digital approaches and technologies that integrate '**Smart Cities**' with '**Transforming Construction**' across the construction supply chain. Our research will contribute to "**Sustainable Smart City Infrastructure**" ensuring that we build sensitively (**SABER**) with respect to our existing built environment and their communities (**ARG**), legislative compliance, procurement, financial sustainability in construction and operation and future value are realised (**RPP**), that systems are smart (**CST**) and low/zero carbon (**CST**, **HySAFER**), and that the buildings are safe (**FireSERT**). Our research will therefore contribute to the goal of industry



meeting the UK's national infrastructure programme target of **£650B** worth of projects by **2025**. In this regard, our strategic priority research areas will focus on:

- *development* of renewable energy and energy efficiency technologies that would facilitate the net zero carbon legislation of the UK.
- *integration and assessment* of decarbonisation approaches allied to future energy scenario developments.
- *delivery* of digital construction and building information modelling (BIM) research that is visionary and complementary with the activities of our research unit.
- *advancement* of the decarbonisation agenda within the commercial real estate and housing sectors.
- *expansion* of research in fire safety engineering, fire behaviour, HFC safety engineering, MSP and waste management.

Our associated targets metrics for the unit in the next REF cycle are to:

- increase the number of staff returned by **30%**,
- increase research income by **25%** with **50%** growth in RC grant awards,
- increase the number of PhD graduates by **25%**,
- expand our research network globally by **25%**,
- increase the number of journal publications by **25%**,
- grow the number of post-doctoral researchers by **25%**, and
- establish new research centre focusing on Digital Construction theme.

We will continue to invest in the technologies, tools and datasets that are needed to realise this vision, and which ultimately will generate algorithms whose co-location will lead to use in industry standard tools such as BIM. Our staff recruitment strategy will support this growth by employing internationally leading experts in the priority research areas. Inter-disciplinary and multidisciplinary approaches will be fundamental to tackling modern societal and development challenges across the built environment and we will utilise our extensive contact networks both locally and internationally to leverage the necessary expertise and specialisms alongside complimentary skills sets and knowledge. The strong internal collaboration between our Research Centres and Research Groups within the unit and through the University will facilitate innovation through knowledge sharing and best practice exemplars via peer reviewed publication and dissemination at conferences and workshops. Strategic investment will facilitate a better alignment with **UK Government Research and Development strategies** and a closer alliance with national and local industry. The impending move of our research base from the Jordanstown Campus to the newly constructed Belfast Campus, the cooperation with local industry will be enhanced in line with Belfast's continuing construction growth and City Deal aspirations.

#### e. Impact Strategy

In REF2014, our strategy for achieving impact was two-fold. Firstly, by developing strong relationships with industry, the professions, regulatory bodies, policy makers and the wider community we delivered demonstrable research activities that shaped the new sustainable built environment and addressed the challenges and complex issues that exist with society. Secondly, we sought to ensure that impact was fully exploited through changes in policy (legislative or regulatory changes) or via product development and innovation. We successfully achieved these impacts in this REF period as evident in the submitted impact case studies (ICS). In brief, RPP's research has informed policy on modern and fairer domestic property tax system both locally and internationally and thus has direct impact on the society and the economy (**PROPTAX ICS**). RPP's research on behalf of Government bodies has also enhanced and shaped housing policy in NI and provided a guideline for strategic growth, societal development and economic regeneration (**HOUSEMARKET ICS**). CST's solar research has contributed to a change in the lifestyle and health in rural communities in sub-Saharan Africa and empowering them through the deployment

of innovative solar technologies (**SOLAR ICS**). HySAFER's research has influenced Safety Regulations, Codes and Standards on HFC based technologies by providing the technical requirements through industry relevant guidance (**HySAFER-RCS ICS**). Finally, FireSERT's research on the redesigning fire-resistant building materials is informing the current policy and fire safety guidelines on resilient infrastructure (**FIRETRAVEL ICS**).

We will continue to grow our support for research with impact in the next 5 years by engaging with the University's Impact Team, Innovation office and Marketing and Communications Team (see **Section 3a**) to disseminate published research outputs more widely to communities. We will also utilise PoC funding for the marketing and commercial exploitation of our research outcomes. Links to industry will be formalised through Non-Disclosure Agreements, options for licensing and spin-out capability will be actively pursued with dissemination to a varied range of stakeholders that can benefit from our research. We will encourage staff to participate in the Ulster Impact Development Series programme (see **REF5a**) to maximise their research impact and to use social media platforms to engage with communities. Communication, connectivity and collaboration are fundamental aspects of the plan to effectively translate impact into products and services and maximise potential societal gains from built environment research.

We have developed an **open access strategy** for our publications in this REF cycle. Our published outputs are deposited in the university managed repository (in PURE) within 3 months of publications and are made available in the public domain. We will encourage staff to publish in high quality open access journals and will continue to allocate funding to cover the fees.

## 2. People

### a. Staffing Strategy

We aim to attract, develop, retain and reward high performing staff. Our staffing strategy is built upon the following process:

- *recruit* staff with an international reputation of excellence that is aligned to our future strategic growth area and research themes,
- *maintain* research strength and expertise via new recruitment addressing the gaps arising from the departure of staff,
- *offer* permanent or long-term contracts to high performing CRS,
- *promote* staff to recognise their success and achievements,
- *create* a supportive environment for all staff that allows for career growth through processes of continuing personal and professional development consistent with the current and future needs of the University,
- *provide* mentoring support to Early Career Academics (ECA) and other ECR research staff to enable them to become an independent researcher,
- *implementation* of the University's Concordat to support the Career Development of Researchers' principles with annual opportunities for advancement, regular training and development, and
- *invest* in research facilities that allows staff to develop and deliver high level research and outputs.

Key successes associated with realising our staffing strategy within this REF period are highlighted below:

- Increased our staff returned (SRR) by **37.5%** with the female participation rate raised by **85%** from the last REF.
- **55.4%** of the staff returned in this REF assessment period are first time participants indicating a well-balanced team of new and experienced researchers.

- **6** Professorial appointments were made in the period through internal academic promotional route (**4**) and new recruitments (**2**) and further **7** new posts were created at lecturer grade.

As shown in **Table 2.1**, we have successfully managed to maintain a healthy balance between staff at different career phases via new appointments and internal promotions to retain our research strength and expertise.

**Table 2.1:** Designation off staff returned within REF2014 and REF2021

| Designation     | REF2014 | % Total head count | REF2021 | % of total head count |
|-----------------|---------|--------------------|---------|-----------------------|
| Professor       | 15      | 37.5               | 13      | 23.6                  |
| Reader          | 6       | 15.0               | 9       | 16.4                  |
| Senior Lecturer | 3       | 7.5                | 8       | 14.5                  |
| Lecturer        | 14      | 35.0               | 22      | 40.0                  |
| CRS             | 2       | 5.0                | 3       | 5.5                   |

We have addressed the gap in expertise created by departing senior Professors (Delichatsios, Yohanis, Gray, Heaney, Hine, Levendis and Van der Krabben) by new Professorial level appointments (**Wiberg**, Chair in Architecture and **Motawa**, Chair in Digital Construction and Building Information Modelling) and via promotion to Professors (**Griffiths**, **Huang Y**, **Clarke** and **Haran**). Sustainability of research growth has been maintained via recruitment of young research active academics with complementary expertise that are aligned to each research group. For example, 4 new recruitments are associated with CST's energy research agenda (**Shah**, heat pump; **Brandoni**, water energy nexus and waste management; **Keatley**, demand side management; **Vorushylo**, energy market modelling and analysis), 1 with RPP (**McElduff**, social-ecological resilience & MSP), 1 FireSERT (**Alam**, Fire safety engineering) and 1 HySAFER (**Shentsov**, hydrogen safety engineering, HySAFER). For CRS appointments, the recruitment reflects success in achieving externally funded research awards, publication records and field of specialisation.

We have also attracted internationally renowned leading experts and practitioners as Visiting Professors, Fellows and Visitors (**Prof Cabeza** (thermal energy storage, University of Lleida, Spain), **Prof Fitzsimons** (planning and development, NI), **Frey** (housing development, Northern Ireland Housing Executive, NIHE), **Prof Neogi** (vacuum glazing, Jadavpur University, India), **Dr Gaitani** (sustainable building design, NTNU, Norway), **Dr Hawksworth**, (hydrogen safety, UK), **Dr Das** (solar thermal, NIT Silchar, India)) who worked closely with our researchers and contributed to shared journal publications.

### Staff promotion

Excellence in research is one of the key indicators for the Academic Promotion Exercise. Staff promotions on the **research and impact** pathway are assessed based on research outputs, successful grant incomes, research supervision, esteem, impact and leadership. Promotional applications are assessed three times a year by a university committee. The university-wide workshops are organised to assist staff who are considering for promotion. In this REF cycle, the following unit staff were promoted through a rigorous assessment process.

- **Griffiths, Y Huang, Clarke** promoted from Reader to Professor
- **Haran**, Senior Research Fellow to Professor
- **Mondol**, Senior lecturer to Reader
- **Zhang, Choi and McCord**, Lecturer to Reader
- **Zacharopoulos, Brennan, Eadie, Coyles**, Lecturer to Senior Lecturer

## b. Staff Development

We have undertaken several initiatives to support our staff for their career development. We allocate time for new staff to attend training needed to develop their career objectives and provide support by reducing teaching load and administration duties during their probation period allowing them to undertake research, fellowships or entrepreneurial activity. In addition, all new academic staff engage with an appropriate Research Centre/Research Group, develop publication plans, become involved in research grants and wider civic engagement. We give preferential allocation in the distribution of PhD studentships to ECA for internally funded studentships supported by experienced supervisory team. Academic staff with a practice-based background are encouraged to register for PhD study in their respective disciplines. Currently **5** FT academic staff (1 female) are registered for PhD study and 2 others have been awarded PhD degrees within this REF cycle. The School '**Staff Development Fund**' ensures that all staff can avail of teaching relief. RD, Senior Professors and Department for Research & Impact provide training to ECR and ECA to support research funding applications and guidance for the submission of high-quality journal articles by reviewing drafts before submission and providing feedback on how to improve an article's REF rating. Where awards are unsuccessful, opportunities for re-submission or alternative submissions are examined with one-to-one mentoring provided by the HoS/RD. Our experienced senior researchers shared their experience on competitive research grant applications and project management skills via organised workshops.

An annual research budget (~**£110K**) is allocated by the Faculty and distributed within six research centres/groups to support staff for various research activities and external engagements such as hosting or organising events, participating scientific committee and attending conferences. Staff have also access to seed funding and pump priming funding to develop international collaboration for large scale funding application (**Smyth** and **Golden** received GCRF pump prime funding to deliver workshops in sub-Saharan countries). All research active staff have bi-annual review meetings with HoS and RD to discuss research progress along with training and support needs.

### Staff training

The University staff mentoring scheme (see **REF5a**) pairs experienced senior staff with early-mid career staff and CRS or those academics wishing to be SRR. Over the two cycles to date, **25** staff have participated as Mentees and **13** senior staff have acted as Mentors. Mentees have received specific support to (i) prepare large scale grant application, (ii) improve quality of research outputs, (iii) develop link with the industries and academic institutions and (iv) apply future leadership fellowship programme. The majority of our staff have benefited by enhancing their research skills on writing proposals including costing, producing high quality outputs, project development, budget management, developing research network and achieving research impact by attending the University organised **RIGOUR (Research Income Grant Opportunities for Ulster Researchers)**, **SOARING (Significance and Originality in Academic Research: Interpreting New Research)**, **IMPACT** (a programme enhance impact to research and evidence the impact and/or define pathways to impact) and '**U Communicate**' events (see **REF5a**). Almost **80%** of our SRR staff (including ECRs/CRs) have participated in these events/programmes. Staff have also participated in PhD supervision training events designed for new and experienced supervisors under '**Supervision Development Programme**' offered by our Doctoral College.

Within this REF cycle, the success of our staff development programme is evident through a number of performance indicators as highlighted below:

- **13** staff became first time PI in this REF period including **8** female staff, i.e. **58%** of female staff returned.
- **20%** of staff who participated in the last REF were promoted to higher positions.
- **5** CRS (RA/RF) were successful in being appointed to a permanent lecturer position.



- 4 staff returned in this REF submission are ECRs.
- 7 PGRs progressed to postdoctoral positions after graduation.

### c. Post Graduate Researcher (PGR)

PGRs are an integral part of the unit's research culture. As shown in **Table 2.2**, during this REF period, a total of **74** PhDs were awarded, which is **20%** higher than REF2014 and includes a high percentage (**39.2%**) of female researchers. Over **107** PGRs have been recruited within this REF period with **71** PGRs currently enrolled in the year 2019-20 (**21.5% female, 69% full time and 39.4% overseas**). We have a strong international PGR community with nationalities including: Australia, Bangladesh, China, Egypt, France, Ghana, India, Iraq, Ireland, Jordan, Kuwait, Lebanon, Nigeria, Norway, Pakistan, Poland, South Korea, Spain, Switzerland, Uganda, and Vietnam. Recruitment of high-quality PGRs is facilitated through an active advertising campaign which includes wide-spread dissemination to the professional sectors, alumni and undergraduate students. School based information sessions and application workshops are facilitated in accordance with the application timescale to actively attract local student applications. Additionally, marketing includes the promotion of PhD opportunities on several social media platforms.

**Table 2.2:** Gender profile and mode of study of PGRs over the assessment period

| Academic year | Total | Female | % of Female | FT | % of FT |
|---------------|-------|--------|-------------|----|---------|
| 2013-14       | 10    | 6      | 60.0        | 9  | 90.0    |
| 2014-15       | 13    | 6      | 46.2        | 8  | 61.5    |
| 2015-16       | 13    | 3      | 23.1        | 10 | 76.9    |
| 2016-17       | 6     | 3      | 50.0        | 6  | 100.0   |
| 2017-18       | 12    | 5      | 50          | 9  | 75.0    |
| 2018-19       | 11    | 3      | 27.3        | 11 | 100.0   |
| 2019-20       | 9     | 2      | 22.2        | 7  | 77.8    |

Recurrent PhD Research Scholarships are funded by two schemes: Department of Education (DfE) and University Vice-Chancellor's Research Studentships (VCRS). These are awarded on a highly competitive basis for advertised topics through an annual call. Around **65%** of awarded PhDs were funded by VCRS and DfE, **14%** externally funded and **21%** self-funded local and international. Additional studentships have been funded through INTERREG (7), EPSRC (6), Korean Government (2) and DfE-SFI (1).

### d. Training and Support for PGRs

We offer excellent training support and research facilities for the unit PGR cohort. Since the establishment of the Ulster Doctoral College in 2017, PGRs can avail of a variety of in-training opportunities through the **Researcher Development Programme** (see **REF5a**) which has approx. **150** training courses designed for researchers to develop their research skills. All PGRs are expected to undertake a **Training Needs Analysis** at the beginning of their studies and to review this on an annual basis, in consultation with their supervisor(s). Employability and Careers also offers a wide range of support for PGRs during their period of study. We also provide unit level training in **discipline specific research techniques and research management** via workshops and/or tutorials and promotes and supports interdisciplinary research with other faculty initiatives such as joint PhD supervision. Workshops include a tailored writing event to support researchers' progression as well as online support and training sessions for technical software such as ANSYS. PGRs are encouraged to attend on-campus Career Fairs to meet professionals and broaden their understanding of how their research can impact on business and industry.

Each PGR has at least two academic supervisors. Occasionally, the supervisory team also include an international expert or expert from other Schools who acts as an advisor. Our PGRs receive additional mentoring support from the School Postgraduate Tutor (PGT) who ensures that all researchers receive pastoral support. Training in relevant research methods and generic skills, in addition to organising progress seminars is provided during the first year of study. A formal Confirmation of PhD assessment is undertaken between 9 and 12 months, with regular progress reports required thereafter. The progress assessment process is facilitated through the PhD Manager online platform and provides a structure to ensure that PGRs are progressing and meeting the necessary milestones required for a timely completion. There are a range of communication channels to support PGRs including a comprehensive online support area, as well as face to face postgraduate researcher forums which are held several times each year. These events ensure researchers can share good practice and discuss solutions to any issues that they may have. Several coffee mornings have been organised to meet and socialise with our PGR cohort.

All PGRs are provided with a designated individual workspace aligned to one of the Research Centres/Groups and access to laboratories as required. All researchers also have access to support from full-time laboratory technicians when required as well as dedicated admin support. All FT funded PGRs are offered a new PC/laptop at the commencement of their studies. We also provide additional funding (ca £900 per annum) to PGRs to purchase lab equipment and undertake specialist training related to their research projects. Our PGRs have participated over **100** national and international conferences in this REF period. Each researcher is also offered the opportunity to present their work at the several annual events to include the Doctoral College Festival of PhD Research, and the regional and national 3 Minute Thesis 3MT® competition.

Our PGRs are given the opportunity to complete the national Postgraduate Research Experience Survey (PRES) and consistently return scores above the national average for all components of survey. In the most recent exercise (2019) the unit level values were: overall satisfaction (84%), research skills (85%), professional development (84%), supervision (85%), resources (86%), and wellbeing (74%). Feedback from this survey alongside that gathered from the researcher forum and seminar events are reviewed regularly to address PGRs' needs.

#### e. Equality and Diversity

Equality, Diversity, and Inclusion (EDI) are valued, actively promoted, and embedded in our research processes and policies. Our REF Code of Practice places people at its centre and ensures barrier free processes to maximise inclusivity and participation in REF, we used it as our roadmap for identifying SRR staff and selecting outputs for REF2021.

Our senior management team ensures that the **Athena Swan Charter** principles are followed and reflect Ulster University's core values of: i) actively promoting a place to work and study where everyone is accepted, ii) striving to be the best we can be, iii) being open, honest and transparent, iv) ensuring people and relationships are central to what we do. The school has recently successfully applied for the **Athena Swan Bronze award**. We adhere to the University's Equal Opportunity Policy to provide equality and diversity of opportunity to all.

The School fully implements all the University's People & Culture (HR) policies and procedures, and the HoS and RD work closely with the School People Partner to ensure that all current staff are treated equally, recruitment panels are gender balanced, and appointments are made solely on merit. The school supports applications to the **University's Returning Carers' Scheme (RCS)** in which staff who have been on leave of absence due to reasons connected to caring can apply for funding to help with their return to work. This includes support for teaching relief, funding for specialist equipment and conference attendance and covering costs to assist with childcare. Staff returning from maternity leave are invited to a **'return to work meeting'** with HoS and RD to discuss the possibility of career breaks, flexible working or reduced hours. Staff can avail of up to 10 **'Keeping in Touch'** days to maintain contact, attend away days, research seminars or training.

Female staff are encouraged to participate in the **Wo/men's Network Mentoring events** which provide a supportive and collegiate space for women to encourage personal and professional learning and development. Within the Faculty Mentoring Circle peer support is also provided for females in STEM, career development advice, and work-life balance. All female staff can also apply to participate in **Advance HE's Aurora** women-only leadership initiative programme.

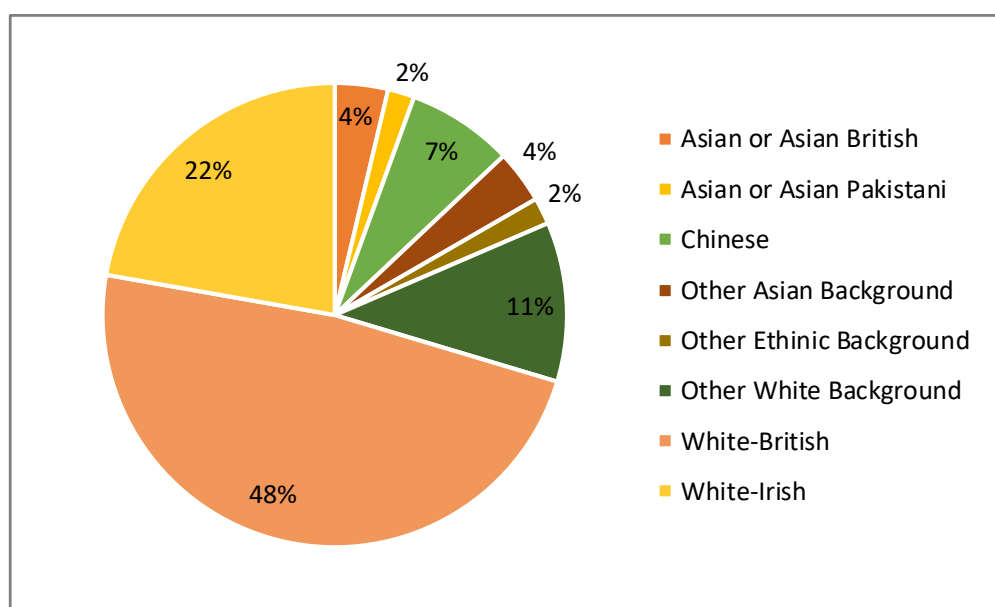
Academic staff members are eligible to apply to take one semester of paid leave, free from normal teaching and administrative duties to focus on research via the University's Sabbatical Leave Policy. The HoS and RD review sabbatical leave applications and the preference is given to support female and ECA members of staff. We ensure that all those on fixed term contracts are aware of the University's redeployment scheme and the HoS and RD have meetings in advance of this process with all relevant staff. Our school specific workload model is highly sensitive to the importance of research led activities and is designed to encourage staff to be research active, a strategy aligned with REF requirements.

The unit is a very diverse grouping and in recent years has become increasingly multi-national with new members of staff joining from a range of different ethnic backgrounds. The male-female ratio within the unit is increasingly balanced with new members joining over the course of this REF cycle predominantly female. **Table 2.3** shows that there has been a significant improvement in terms of female participation in this REF cycle compared to REF2014 with almost the double the numbers of female staff returned.

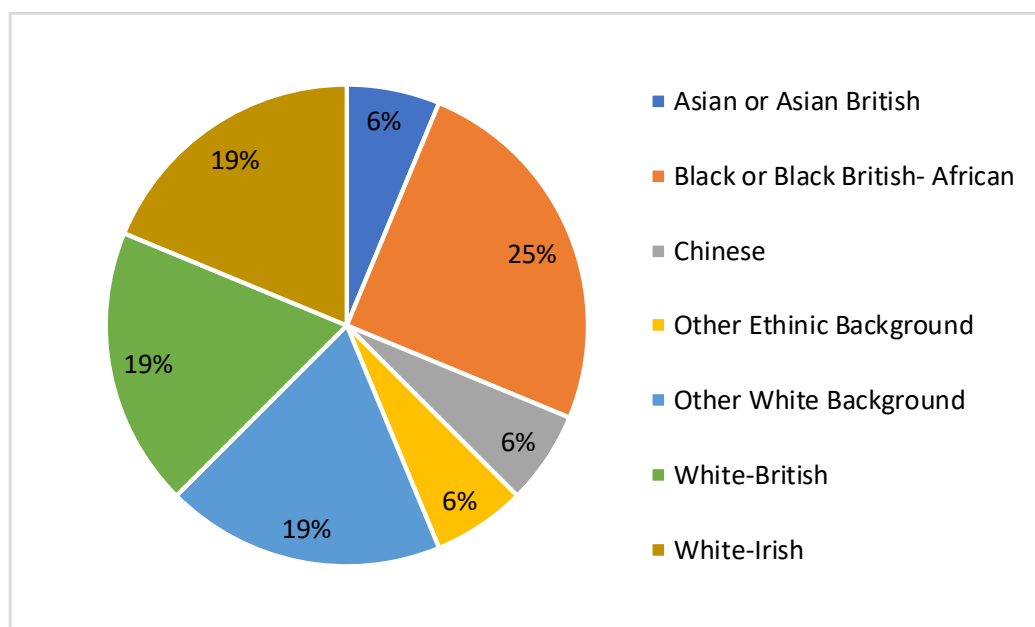
**Table 2.3:** Gender distribution of staff who participated in REF2014 and REF2021

| REF period | Total (Head count) | Male | Female | % Female |
|------------|--------------------|------|--------|----------|
| REF 2014   | 40                 | 33   | 7      | 17.5     |
| REF2021    | 55                 | 42   | 13     | 23.6     |

Our 7.6%, 32.1%, 35.8% and 24.5% of staff returned in this REF are within the age group of 26-35, 36-45, 46-55 and above 56 years, respectively indicating a good age diversity. The unit also shows a good mix of staff ethnicities returned within this REF cycle (see **Figures 2.1** and **2.2**). In July 2020, **22%** of staff was international, **21%** of all academics and this growth in our international staff was key part of our staffing strategy to broaden our international expertise with varied experience and research skills. Likewise, **62%** of CRS are international, a proportion which exceeds the UK population figure which is **14%** (UK Migration Observatory, 2018) and **38%** are female.



**Figure 2.1:** Ethnicity profile of SRR staff members participating in this REF submission.



**Figure 2.2:** Ethnicity profile of currently employed CRS

### 3. Income, Infrastructure and Facilities

#### a. Income

As outlined previously, we have been highly successful in generating external funding in this REF cycle in a competitive funding environment and increased our research spend by **74%** compared to last REF with total spending of circa **£22.9M**, (**£9.7M** higher than REF 2014) (see **Table 3.1**). The spend per FTE in this REF cycle is **25%** higher than REF2014 with an annual average spend **24%** higher (see **Table 3.1**). Our RC income grew by **91%** and EU funding from government bodies and other sources by **118%** (see **Table 3.2**).

Over the period, total **327** funding applications were made with a total requested value of ca **£81M**. A total of **128 grants** were awarded indicating a high success rate of **39%** and **28%** in terms of grant applications and funding amount received, respectively. Of the total income obtained, **45.5%** was generated from **11** large scale projects (>£500K), **47.6%** from **61 mid-scale** (£100K to £500K) and the rest from **56** small scale (<£100K) awards highlighting our involvement in projects at a range of scales.

**Table 3.1:** Comparison of Research spend from REF2014 to REF2021

|                               | REF2014     | REF2021     | Increase (%) |
|-------------------------------|-------------|-------------|--------------|
| Research Spending (£)         | £13,207,032 | £22,962,925 | 73.9         |
| No of FTE                     | 38          | 52.8        | 38.9         |
| Research Spending/FTE (£/FTE) | £347,553    | £434,903    | 25.1         |
| Research spending per year    | £2,641,406  | £3,280,418  | 24.1         |



**Table 3.2:** Research spend in terms of funding categories.

| Income Source                                      | REF2014    | REF2021     | Increase (%) |
|--|------------|-------------|--------------|
| Research Councils, Royal Society, British Academy  | £3,568,029 | £6,796,261  | 90.5         |
| UK-based charities (open competitive process)      | £227,576   | £398,074    | 74.9         |
| UK-based charities (other)                         | £503,489   | £77,062     |              |
| UK central government bodies and local authorities | £3,178,350 | £3,366,382  | 5.9          |
| UK industry, commerce and public corporations      | £451,062   | £1,009,780  | 123.9        |
| UK central government tax credits                  |            | £247,000    |              |
| UK other sources                                   | £210,193   | £283,616    | 34.9         |
| EU government bodies and EU other sources          | £4,778,504 | £10,399,912 | 117.6        |
| EU-based charities (open competitive process)      | £3,781     | -           |              |
| EU industry, commerce and public corporations      | £7,678     | -           |              |
| Non-EU industry, commerce and public corporations  | £24,292    | £9,594      |              |
| Non-EU other                                       | £254,078   | £375,243    | 47.7         |

### Research Council

Our enhanced collaboration with other UK universities (See **Section 4b**) and industries has led to success in **20 UKRI** grant awards (**EPSRC, ESRC and AHRC**) and represents **30%** of our total research spent (circa **£6.8M**). CST's research in heat pump, thermal energy storage and distributed network has secured **5** EPSRC funded research awards:

- (i) **LoT-NET (£1.3M)** – delivery of a cost-effective near-zero emissions solution for heating and cooling needs of UK buildings and industrial processes from waste heat.
- (ii) **I-STUTE (£832K)** – develop a portfolio of technologies to deliver heating and cooling cost-effectively.
- (iii) **4S-DHW (£376K)** – develop an affordable domestic hot water system by combining innovative controller, heat pump and thermal storage technologies.
- (iv) **DELTA PHI (£269K)** – improving efficiency of the industrial processes by effective use of heat distribution via heat pump technology.
- (v) **Comfort and Climate Box (£202K)** – develop an energy package combining heat pump, storage and controls.

Three projects '**SolaFin2Go**' (**£245K**), '**SolaNetWork**' (**£211K**) and '**SwanaSmartStore**' (**£66K**) funded by EPSRC under the Energy Catalyst programme have allowed the CST team to design, develop and deploy a hybrid solar home system providing affordable access to clean energy in diverse rural communities in Sub-Saharan Africa.

HySAFER has led a multidisciplinary team of researchers consisting of industrial experts and organisations from the UK (Warwick, Bath), USA, France, China, Korea and Australia in the EPSRC funded "**Integrated Safety Strategies for Onboard Hydrogen Storage Systems**" (**£970K**) which is informing the wider public to underpin safety of HFC technologies. The team has also awarded **£552K** for **7** PhD studentships in the **CDT SusHy** programme.

RPP researchers have collaborated in Administrative Data Research Centre (**£1.1M**) project funded by ESRC to create a database to improve public service provision including education, housing, health and social care.

ARG received two AHRC funding awards for the '**Communities as Constructs of People and Architecture**' (£312K) project examining the architectural legacy of the troubles in Belfast's most deprived urban areas and the '**Divided Pasts - Divided Futures**' (£202K) project that investigated the impact of historical and heritage data on the urban design.

#### EU Government bodies and other

Our strategy to expand collaboration internationally with both academic and industrial partners has resulted in the award of highly competitive European funding totalling **£10.4M** (See **Table 3.2**) from EU Govt bodies and other sources which includes **32** awards funded through CEC FP7, CEC H2020, CEC Coal and Steel and CEC NPP Northern Periphery and **6** via INTERREG VA programmes contributed to **45%** of our total spend.

Several EU grants awards have supported CST's energy research. CST is leading the **£5.2M** INTERREG VA **SPIRE 2** project in energy storage and renewable energy technologies contributing to the region's research and innovation capacity by creating a cross border Virtual Research Graduate School to advanced energy storage solutions. CST's expertise on phase change material and heat pump design has been used to develop multifunctional building façade in the **IDEAS (£510K)** project and vacuum glazing techniques for fire resistance glazing systems in building facades and experimental characterisation at FireSERT laboratory (**EENSULATE, £592K**). In the **CHESS-SETUP (£159K)** project, our researchers have developed an integrated solution combining heat pump, solar thermal technology and seasonal heat storage to supply heating and hot water and also tested the performance of a high temperature heat pump system in the associated **CHESTER (£203K)** project. Along with **13** other universities, the CST team has delivered training programme for the PhD students across Europe on the thermal energy storage technologies under **INPATH-TES Programme (£128K)**.

Building upon excellence in techno-economic modelling using the in-house developed **ECLIPSE** model and Life-Cycle Assessment for new energy systems, CST researchers have collaborated in **3** large scale EU projects:

- (i) **DIRPRIMCOAL (£109K)** – improving the environmental performance of a direct coal liquefaction process.
- (ii) **LIG2LIQ (£119K)** – developing an economically efficient concept to produce liquid fuels from the lignite and solid fuel recovered from municipal waste.
- (iii) **SCARLET (£188K)** – conducting a techno-economic and environmental assessment of coal and lignite fuelled power plants and cement and steel production plants.

HySAFER has participated in **6** large scale multi-partner EU funded research projects on HFC technologies:

- (i) **NET-Tools (£227K)** – developed new e-education methods and ICT-based tools for education and training in HFC technologies.
- (ii) **HyResponder (£250K)** – leading a train the trainers programme on hydrogen safety supporting the commercialisation of HFC technologies.
- (iii) **HyTunnel-CS (£338K)** – advancing innovative fire prevention techniques for HFC cars.
- (iv) **HYLANTIC (£166K)** – Atlantic network for renewable generation and supply of hydrogen to promote high energy efficiency.
- (v) **PRESLHY (£204K)** – Pre-normative research for safe use of liquid hydrogen.
- (vi) **SUSANA (£249K)** – support to safety analysis of HFC technologies.

RPP has attracted **4** major EU grant awards:

- (i) **CRREM (£196K)** – engaged with the industry and policy makers across Europe to inform the development of decarbonisation pathways at building level.

- (ii) **INSPEC2T (£147K)** – developed a sustainable framework for community policing that effectively addresses and promotes collaboration between the police and the community.
- (iii) **ASGARD (£420K)** – lead by School of Computing and Informatics, to create a database on Forensics, Intelligence and Foresight in supporting a community of Law Enforcement Agencies.
- (iv) **INTACT (£186K)** – investigation of the socio-economic impact of extreme weather events on the critical infrastructure.

FireSERT has been involved in **3** multi partnered EU projects:

- (i) **ELISSA (£286K)** – development of nano-enhanced prefabricated lightweight steel skeleton/dry wall systems with improved thermal, vibration/seismic and fire safety performance.
- (ii) **TRAFIR (£120K)** – experimental and simulation study to improve structural safety contributing to safety guidance for large scale buildings.
- (iii) **LOCAFIplus (£38K)** – experimental testing of steel columns that can protect buildings under localised fires.

### UK Government Bodies and Local Authorities

We work closely with government bodies and local authorities to support the sustainability agenda, influence local policies and develop the local economy through our research. In this regard, RPP has continued to secure funding through **NIHE (£612K)** and the **Progressive Building Society (£190K)** to inform policy development as well as the exploration of new and emerging housing market themes. Funded by Enterprise Ireland (**£511K**), CST researchers provided innovative solutions to monitor total energy consumption during manufacturing process to help to reduce energy in the stage 2 and 3 **TEMPO** research projects.

Funding through the **Invest NI PoC programme** (total **£357K**) has supported our researchers to develop **4** projects with commercial potential:

- (i) development of a prototype tank for hydrogen storage which is able to withstand any fire without a catastrophic rupture,
- (ii) fabrication of a hybrid building integrated solar thermal façade,
- (iii) design of a smart, cost-effective Fire-Blast Protection system, and
- (iv) manufacture of new optimised hybrid hydrogen storage tank using composite materials.

### UK Industries, Commerce and Public Corporation

Our strategy to support local industries and businesses is evident through **8** industry focused research projects funded by the **Invest NI CASE** scheme with total funding of just over **£1M** and through the delivery of over **50** innovation voucher projects (**£250K**). These industry led projects involved development of multifunctional building façades technologies (**CE-SEA, £202K**); design, development and demonstration of a low-cost solar thermal collector for Senergy Ltd (**Senergy demonstrator, £197K**); development of a concept for a mobile containerised battery storage system to be used as a 'floating' resource in NI Water sites (**AQUAFLEX, £182K**); creation of a carbon neutral development using on-site renewable and sustainable energy sources (**Foyle River Gardens, £172K**); laboratory testing of biofuels generated from agri-food chain (**Sustainable Underutilised Biomass Boiler Fuels, £120K**); and investigated pelletisation techniques for mixed fuels including biomass and various fossil fuels in '**Pelletisation**' (**£45K**) project. In collaboration with Nottingham University and Trinity College Dublin, SABER Researchers have contributed to road safety design guidelines funded by National Roads Authority (**£97K**). These projects have had significant impact on the development of local economy via creation of new industries and innovations.

Our research has contributed to local communities and societies in the areas of spatial planning, fire safety, community development, distributed energy and flood protection and has secured **£563K** research income through UK charities such as Royal Society, Royal Institution of Chartered Surveyors, Royal Academy of Engineering, Royal Institute of British Architects (RIBA) Research Trust. Funded through Korean Government (**£477K**), FireSERT is delivering two projects: designing fire resistance protective clothing and developing emergency response training facilities. More than **£400K** of external donations have been received from Gerard O'Hare Foundation, Belfast Harbour Commissioners and a number of commercial property agents. This funding has supported short-term research assistant posts, created full time PhD positions and was used for undertaking industry related research for the sector.

### Future Funding Strategies

To continue our success in growing research income, we will adopt a strategy built upon following approaches:

- *Retain/renew* existing funding awards and seek to expand into new areas with established funding partners and research consortia.
- *Give* staff the time and funding resources from our research budget to develop applications.
- *Develop* interdisciplinary and multi-contextual collaboration to deliver novel, innovative, complex and ground-breaking research projects.
- *Exploit* PoP/PoC funding to develop large scale commercially focused projects.
- *Support* staff for UKRI first grant applications and Future Leaders programmes.
- *Engage* with professional bodies notably those with global reach.
- *Work closely* with University's Global Grant Manager, Strategic Research Development Manager and Interdisciplinary Theme Lead to develop new local and international partnerships to secure global funding.
- *Utilise institutional grants* (Research Development Strategy fund, Collaborative Research Fund and GCRF pump priming) to prime and develop large new grant applications.

### b. Infrastructure and Facilities

Our infrastructure strategy is targeted to sustain growth in strategic priority areas and to invest in technical staff to support our laboratory provision for staff and PGRs. Over this REF period, we have invested over **£1.5M** in the research infrastructure and facilities via externally funded research projects and internal support funding. In addition, interdisciplinary collaboration with other schools has facilitated the sharing of laboratory facilities such as NIBEC (Nanotechnology and Integrated Bioengineering Centre) for the ALICE project.

A full suite of ANSYS software licences was purchased (~**£100K**) for HySAFER to facilitate CFD modelling research on hydrogen safety design. Collaboration in Ulster-QUB **Kelvin-2** project will allow us to utilise the new **£5M** EPSRC funded High Performance Computer (HPC) facility and high-speed network to assist HySAFER's simulation-based research work. HySAFER Research facilities also include powerful processor computers (**1056 CPUs across 15 UNIX workstations**) and specialised software for modelling and simulation of HFC technologies. The NET-Tools project provided free access to online "**e-Laboratory**" and **IT training tools** on hydrogen safety.

New facilities within CST include a high temperature heat pump and oil-viscosity test rig (**£150K**); upgradation of existing 'Terrace houses' as a living lab (**£50K**) with roof-top PV panels, battery storage and heat pump with thermal storage for monitoring demand side load profile. Investments were made to maintain our state-of-the art solar simulator facility which has been used extensively for industrial research such as for testing performance of photovoltaic mobile ice-cream freezer for Unilever, Senergy polycarbonate base solar collectors and Kingpans's semi-transparent solar PV module. An outdoor test facility to characterise solar thermal systems was also funded through



Invest NI CASE project. An electric vehicle (EV) was purchased to study the impact of EV in the grid electricity network and future decarbonised homes.

FireSERT has world class laboratory facilities including a full-scale test rig for fire testing of a range of buildings and materials. Around **£50K** has been spent on new equipment including a UV/Vis spectrophotometer, OPUS 8.2 Software and Eye Tracking: Tobii Pro Glasses for precise measurement of participant's behaviour in emergencies including spatial and situational awareness.

To support RPP's ongoing research on real estate, planning and housing market analysis, around **£80K** has been spent on new data bases, software and equipment (GIS, Laser Scanner). **ArcGIS** software has been a key enabling tool in showcasing and visualising research findings. New database and licensing agreement for example **Pregin's** databases for infrastructure and real estate; **MSCI** database containing performance indicators on the commercial property market around the world; **INREV** database which comprises key information on the European unlisted real estate funds sector and, **E-views** for statistical modelling and econometric analysis has permitted researchers to utilise data in a series of external research commissions and journal publications.

The state-of-the art Highway Laboratory facilities at SABER are used for predicting the performance of highway construction materials and research projects related to racetrack performance; a hydraulics lab for research on flooding; and concrete laboratory facilitates for testing construction materials. New facilities (~**150K**) include Acoustic Doppler Velocimetry, Ford Custom van, VI-grade simulation software for modelling of tyre/surface interaction, laser scanning device, photographic equipment, Cooper accelerated polishing machine, Digital Surf Mountains Map software, thermal camera, InstaPro 360-degree camera and other smaller equipment.

We have spent over ca **£200K** for a new Model-Making Workshop and a suite of **15 new CAD PC's** at the Belfast campus to support ARG's ongoing research activities and around **£75K** on various software packages and licenses across the unit.

### Research Support Structure

Our research infrastructure is supported by the School, Faculty, and Central Departments. Our daily research operational activities are managed by **4** dedicated admin staff and technical activities are supported by a team of **14** highly experienced technicians. In terms of R&D support, we have **pre-bid grant support** and **post-research award support** (drafting contracts and collaboration agreement, signing of grant contracts and managing finance) provided at both **Faculty and Institution level**. Our faculty dedicated R&I Research Development Manager offers support to grant application activities such as budgeting, resource allocation and proposal submission. The commercial activities of our research (IP management, licensing, support for spin-out company, inventions disclosures) are managed by Innovation Ulster Ltd.

### 4. Collaboration and contribution to the research base, economy and society

As indicated throughout this statement, collaboration with universities, research institutions, government bodies, private sector and industries is integral to our research strategy to address key societal, environmental and policy-based challenges. Such collaborations have enhanced our ability to share and exchange resources. Key indicators of success in research collaborations in the REF period are highlighted below:

- *Partnerships* with **175** external bodies in collaborative research projects (**68** universities and research institutions outside UK and Ireland, **35** universities within UK and Ireland, **17** government bodies and **55** industries) from across **26** countries worldwide.
- *Interdisciplinary collaborations* with **10** other schools within the university.
- *Co-authorship* with **179** external academics from **103** institutions worldwide.

- **53%** of our publications are co-authored with international collaborators, **15%** with national based partners and **30%** institutional (based on Scopus).

#### a. Interdisciplinary Research

Pursuance of interdisciplinary research is fundamental to addressing the complex issues that relate to research in the built environment addressing societal need. We work closely with our Interdisciplinary Theme lead who promotes and identifies opportunities for greater cross-school collaborations across units, as well as with external partners. Within this REF period, we have delivered over **£3.5M** of funded research in collaboration with **10** schools within the university. Collaboration with Computing, Engineering and Intelligent Systems and Biomedical Science has allowed us to integrate our research with specialised research fields like IT, Big data analysis, computing simulation (e.g. **TEMPO, INTACT, ALICE, Kelvin-2**). Social policy, human behaviours and health and well-being are key areas that have been addressed in the unit by pooling research expertise from Social & Policy Sciences, Law, Nursing, Art and Psychology (e.g. **INSPEC2T, House prices, rents and affordability, ASGARD, Divided Pasts - Divided Futures**).

#### b. Academic Collaborations

Collaboration with internationally renowned academics and Research Centres is an effective means to enrich our research culture via the exchange of ideas, knowledge and complementary skills, delivery of joint scholarly outputs and staff-student exchanges. We have extended our collaboration with leading UK universities to deliver a range of UKRI funded research projects (see *further details in Section 3a*). For example, HySAFER has developed partnerships with **5** universities within the UK to deliver EPSRC CDT programme in 'Fuel Cells and their Fuels' (**£4.4M**) and with **3** universities in CDT-SusHy project (**£6.5M**). The team is a part of the SUPERGEN H2FC project (**£3.1M**) in partnership with University College London, Birmingham, Newcastle University, University of St Andrews, Imperial College London and Bath.

CST's heat pump researchers have partnered with Loughborough, Warwick, and London South Bank Universities to deliver two large scale research projects (4S-DHW (**£1.2M**), LOT-NET (**£5.4M**) and involved in End Use Energy Demand Centres along with **9 UK universities** to investigate thermo-economic performance of heat pump and thermal energy storage technologies. These collaborations have allowed for the sharing of research facilities within universities to deliver high level experimental based research projects.

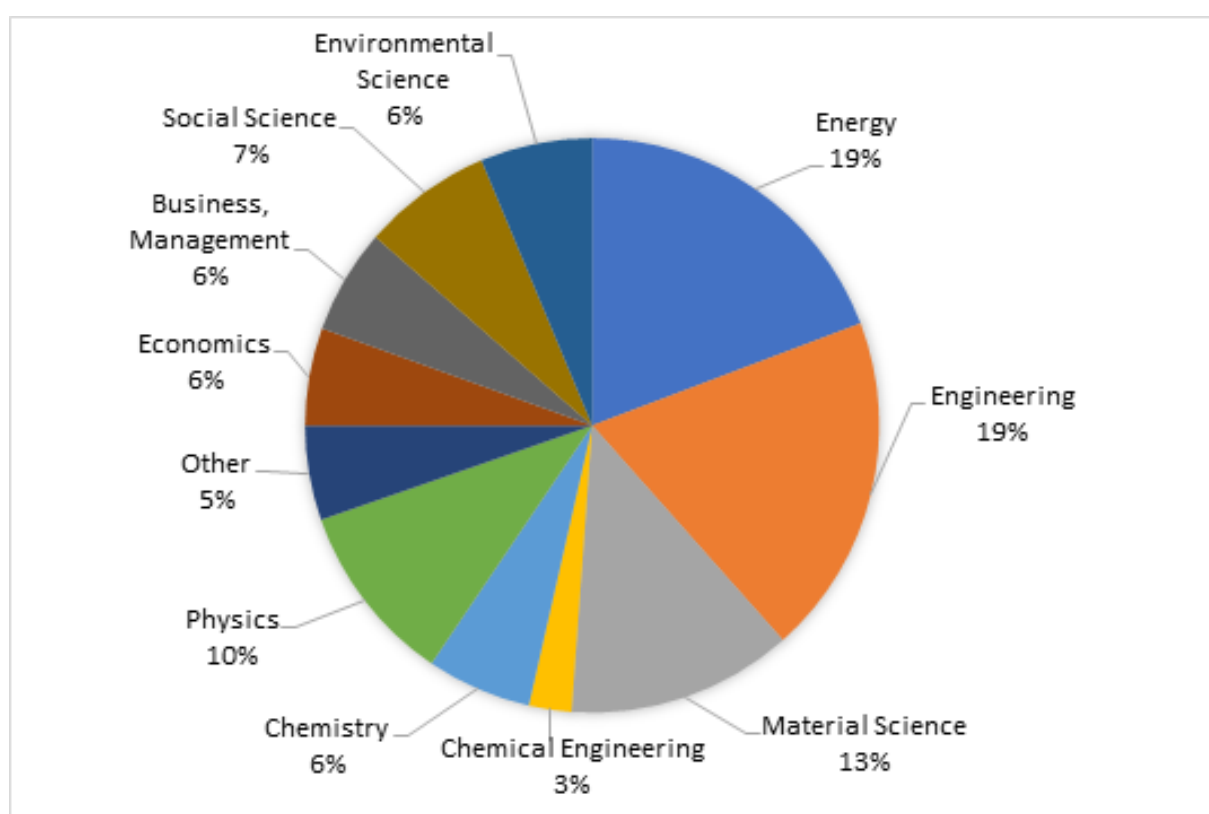
FireSERT has collaborated extensively with international research groups, including, Tokyo University of Science (Japan), and FM Global (USA), Coimbra University (Portugal), Liege University, Belgium, ArcelorMittal (Luxembourg), Lorraine University (France), Poitiers University (France), The British University in Dubai (UAE) and Efectis (France). The group is also providing research data related to combustion and fire to the International Centre for Numerical Methods in Engineering (CIMNE, Spain) for the development of Kratos CFD code, an open-source software which is available for a wide community of industry users.

RPP's ongoing research with Griffith University (Australia) is priming a proposal to the Australian Research Council on strata homes. RPP researchers are collaborating with University of Alicante and Tilburg University in CRREM project to promote decarbonisation agenda within the commercial real estate sector. A series of EU projects in the infrastructure and security domains have seen collaborations with the United Nations University (Japan), Stuttgart University, University of Konstanz, University of Amsterdam, University of Milan, University College Dublin and Dublin City University. RPP researchers have participated in the **£6M** ESRC funded UK Collaborative Centre for Housing Evidence (CaCHE) consortium which consists of **14 UK** based institutions addressing issues related to the UK's housing problems. Expansion of RPP's research on MSP has led to a strategic partnership with Aalborg University, University of Oldenburg, University of Liverpool, University of Nantes, Leibniz Institute for Baltic Sea Research, Breda University of Applied Sciences, and the Finnish Environment Institute. Through this partnership, the team is contributing to the development of new innovative approaches to higher education and training on MSP.

ARG's research employs multidisciplinary methodologies bringing together expertise from architecture, photography, urban planning, conflict studies, social policy, and history. Recent projects have brought together collaborators from London School of Economics, University of California, Irvine, Kingston University and range of community organisations.

International academic collaboration has been developed via the **Royal Society International Exchange Scheme** with University of Wyoming (China) to investigate impact of flooding on bridge construction, and Chinese Academy of Sciences to develop distributed energy storage systems; **UK India Education & Research Initiative** with IIT Guwahati (India) to carry out experimental work on nanoparticle based liquid biofuels for engines and **Royal Academy of Engineering** funding to conduct an experimental study on large scale hydrocarbon fire by using laboratory facilities at University of Science and Technology of China.

These academic collaborations have led to the publication of **270** journal articles co-authored with external researchers. In this regard, our research has contributed to a range of subject disciplines as shown in **Figure 4.1** which indicates the diversity and interdisciplinary nature of our research.



**Figure 4.1:** Research publications in different subject area (based on Scopus)

### c. Collaboration with Government bodies, Private Sectors, Stakeholders and Industries

Research carried out on behalf of government departments/agencies/stakeholders has had impact on public sector decisions and influences policy across matters pertaining to spatial planning, housing, property, energy, land and water. Non-academic partnerships has been developed with councils and other stakeholders such as GRESB (Netherlands), IIO (Austria), MSCI (UK), GLIO, (Belgium), Community Places (NI), Stichting Waag Society (Netherlands), NI Water, Donegal County Council, Antrim & Newtownabbey Borough Council, Police Scotland, Greater Whitewell Community Surgery, Lower Oldpark Community Association, HR Wallingford, Trilateral research, Lancashire Constabulary, the NI Police Service, Belfast City Council and Belfast Harbour Commissioners.

Through our engagement with the private sector and professional bodies/associations such as Chartered Institute of Housing, Royal Town Planning Institute, Royal Institution of Chartered Surveyors, International Association for Hydrogen Safety, we are influencing current and future policy, practice, standards and legislation. HySAFER is a co-founder of the International Association for Hydrogen Safety and participates in activities of the International Standardization Organisation ISO/TC197 "Hydrogen technologies". CST is working with the NIHE (one of the UK's largest social housing providers) on field trials to evaluate low carbon retrofitting of social housing stock. In partnership with NI Fire and Rescue Service (NIFRS), FireSERT is developing a database for fire related deaths in NI to be used as a key regional resource. SABER has collaborated with the Road Authorities of England, Ireland and Denmark.

Industrial collaboration within and outside UK has been established through funding sources such as FP7/H2020, UKRI, Innovate UK, Invest NI and Enterprise Ireland and has delivered projects that have commercial interests and thereby influenced the local economy. In the SPIRE 2 project we have collaborated with **14 businesses** including Arbarr Group, Sunamp Ltd, Glen Dimplex Ltd, AES Kilroot Power Ltd, Causeway Coast and Glens Borough Council, Community Energy Scotland, B9 Energy Group, Climote, SSE plc, Energia, ESB Innovation, Ulster Farmers Union and The Authentic Food Company. In partnership with dpSun, Solaform Ltd and Empowerd Pty we are developing a sustainable business model for a solar home system for customers with diverse economic background. Our researchers have provided a specialised review on the fire safety design strategy for the UK buildings and beyond for example DPP Belfast, Teesside University and the UEA International City project. RPP has developed research collaborations with industry including TNO, Deltares, CGI (Netherlands), VTT (Finland), KEMEA, Satways (Greece), Dragados (Spain), GLIO (Belgium), Aditess (Cyprus), Future Analytics Consulting (Ireland), VICOMTECH (Spain) and the Stiftelsen Norges Geotekniske Institutt (Norway). HySAFER researchers have extended their collaboration with industries in multi-partnered European projects (see **Section 3a**) such as Energy Limited (UK); Air Liquide (France); UlemCo Ltd (UK); APRIA Systems (Spain); Auriga Energy Limited (UK); A. Silva Matos (Portugal); Pure Energy Centre (UK); Pro-Science (Germany) providing solutions to HFC cell safety technologies.

#### **d. Wider Academic and Contributions to Professions and Learned Bodies**

We have made valuable contributions to the sustainability of the disciplines within the unit through active engagement with professional bodies and international organisations, keynote addresses at conferences, membership of Journal editorial boards and participation in international networks. Staff in the unit are members of relevant professional bodies such as *Energy Institutes (Griffiths)*, *Chartered Institution of Highways and Transportation*, *Institute of Asphalt Technology (Woodward)*, *Engineers of Ireland (Eadie)*, *Chartered Institution of Building Services Engineering (Smyth)*, *The Institute of Concrete Technology (Magee)*, *Institute of Quarrying (Woodward)*, *The Concrete Society (Magee)*, *European Real Estate Society (Berry)*, *Institution of Civil Engineers (Solan)*, *Association of Civil Engineering Departments (Eadie)*, *International Real Estate Society (McGreal, Berry)*, *Royal Institute of British Architects (Murphy, Golden)*, *Royal Society of Ulster Architects (Murphy)*, *International Centre for Local and Regional Development (Rafferty, Ritchie)*, *Royal Town Planning Institute (Berry)*, *America Real Estate Society (Berry)*, *European Academy of Science (Hewitt)*.

Our staff sit on a number of policy forums, commissions established by local government departments and local authorities and involved in national and international expert panels, advisory committees and working groups making strategic decisions on policy, standards and government targets, examples include:

- Molkov, Chair of Education Committee of International Association for Hydrogen Safety.
- Berry, Executive Director and Board Member of European Real Estate Society.
- Haran, Member and Research lead NI Better Housing Forum.
- Motawa, Member of the European Group for Intelligent Computing in Engineering.



- Hyde, Member of Independent Insulation Performance Panel for Cavity Wall Research Project, NI.
- Richie and McElduff, Member of Irish Sea Maritime Forum Steering Group.
- Adair, Chair of Independent Tower Block Reference Group, NI.
- Davis, Chair of International Association of Assessing Officers.
- Griffiths, Member of NI Building Regulations Committee.
- MacIntyre, Member of Environmental Protection NI.
- Woodward, Member of British Standards committee for B/510/05 Surface characteristics and BS 8870 High Friction surfacing.
- Eadie, Member of International Working Group on E-Business in Construction.

Staff members are also contributing to scientific, technical and international advisory boards and are members of organising committee for international conferences (for example WREN 2018 (Huang M), EUROSUN 2016 (Mondol, Zacharopolous), SDEWES 2019 (Zacharopolous), IFIRESS 2015 (Boyce), IAFSS 2017 (Boyce), SOLARIS 2018 (Smyth), First International Conference on Smart Cities (Woodward), International Conference for Road Engineers (Woodward), MAIREINFRA1 2017 (Woodward), 6th and 7<sup>th</sup> ICONFBMP (Woodward); ICDCS 2016 (Magee); ARCC-EAAE 2015, 2018 (Golden), AREUEA 2016 (McGreal), ERES 2014 (Berry). Hewitt, Shah, Huang M represent UK in IEA Annex 46 and 48 (Domestic Hot Water Heat Pumps and Industrial Heat Pumps, Second Phase respectively) and Annex 55 (Comfort and Climate Box); Houlihan Wiberg in IEA Annex 72 (Assessing Life Cycle Related Environmental Impacts Caused by Building) and Mondol and Zacharopoulos in IEA Task 63 (Solar Neighborhood Planning); EU COST Action TU125 (Smyth, Zacharopoulos, Mondol).

Our staff hold Visiting Professor positions in national and international institutions, for example: McGreal (University of South Australia and Universidad de Alicante); Hewitt and Huang Y (Institute of Engineering Thermophysics, Chinese Academy of Science); Huang Y (National Compressed Air Energy Storage R&D Centre, Gui-Zhou); Huang M (Beihang University); Molkov (College of Engineering and Physical Sciences, University of Birmingham); Davis (Masaryk University), Motawa (Mansoura University, Egypt).

Our staff serve on the editorial boards of scholarly journals in the built environment disciplines:

- **Editor in Chief:** International Journal of Ambient Energy (Hewitt); Journal of Structural Fire Engineering (Ali); Journal of Financial Management of Property and Construction (Davis).
- **Editorial Board Member:** Journal of Property Research and Journal of European Research (Adair, Berry, McGreal); Journal of European Real Estate Research and Journal of Real Estate Portfolio Management (McGreal); Journal of Property Research (Berry); Journal of Corporate Real Estate (Hemphill), Fire and Explosion Safety (Molkov), Archivum Combustionis (Molkov), Hydrogen (Molkov), Fires and Emergency Situations: Prevention and Control (Molkov), Combustion Explosions and Shock Waves (Molkov), Fire Safety (Molkov); Proceedings of the Institution of Civil Engineers (Brandoni); Sustainable Building Journal and Journal of Renewable Energy (Mondol); Journal of Energy Reports (Huang MJ); Journal of Property Tax Assessment and Administration (McCord M); Renewable Energy (Smyth, Zacharopoulos), Fire and Materials (Boyce), Journal of Structural Fire Engineering (Nadjai, Boyce), Journal of Financial Management of Property and Construction (Haran), Environmental Research: Infrastructure and Sustainability (Houlihan Wiberg), Applied Sciences (Ali).
- **Guest Editor:** Infrastructures Journal (Woodward); Energies Journal (Mondol, Shah), Entropy Journal (Mondol, Smyth).

Our staff have contributed to proposal review for different funding bodies such as EPSRC, ESRC, H2020, The Netherlands Organisation for Scientific Research, Royal Society, South African National Research Foundation, Royal Institution of Chartered Surveyors Education Trust, Natural

Sciences and Engineering Research Council of Canada, Czech Science Foundation, Natural Science Foundation of China, British Council.

#### d. Awards and International Recognitions

Our staff have received national and international awards and recognition for excellence in their contributions to research:

- McGreal, the International Real Estate Society Achievement Award (2017) and the Pacific Rim Real Estate Society Achievement Award (2018)
- Hewitt, World Renewable Energy Network Pioneer Award (2018)
- Eadie, Bulgarian Scientific and Technical Union of Civil Engineering Award (2018)
- Hyde, Best paper award at ICSBDC 2017 and ICHREET 2018
- McCord M and Davis, Distinguished Research and Development award for best paper (2017)
- McGreal, Best Journal paper award, Pacific Rim Property Research Journal (2015)

#### e. Conference, Seminars and CPD Activities

In contributing to the research community, the unit has hosted several international conferences, seminars and training programme during the assessment period. HySAFER has regularly organised the biennial **International Conference on Hydrogen Safety** (2015, 2017 and 2019) and the triennial **International Seminar on Fire and Explosion Hazards** (2016, 2019); the **International Seminar on Fire and Explosion Hazards** (2016, 2019); an **International School “Progress in Hydrogen Safety”** (2019). FireSERT organised the “**10<sup>th</sup> International Conference on Structures in Fire**” in Belfast which was attended by 250 delegates from 33 countries. CST has hosted a closing conference for the **INTERREG IVA SPIRE** project at the **21st ICE/IEEE International Technology Management Conference** in Belfast with over 170 delegates. CST has also made concerted efforts to shape the EU research agenda in energy storage and demand side response through co-hosting a **Sustainable Energy Week event** (15-19 June 2015) in Brussels which was supported by Invest NI; the **First International Conference on Building Integrated Renewable Energy Systems** in Dublin (2017) and the **BESECURE** project event to disseminate research outcomes on urban security (2015).

We have organised workshops, training programmes and outreach activities to educate professionals and to engage with wider research community. For example:

- FireSERT organised an international workshop on the cost-effective design solutions for structural fire delivered to fire engineering professionals in Dublin (Nov 2018).
- RPP’s hosted the **European Real Estate Society’s Industry** seminar on “Recapitalisation of the European real estate market and lessons from Ireland” (Oct 2014).
- SABER delivered a workshop in conjunction with **Engineering Ireland** to explore the vulnerability and management of masonry arch bridges under major storm events (Jan 2019).
- CST organised three workshops under **ALICE** project to disseminate knowledge on the impact of wastewater management on society and environment (Sept 2019).
- CST hosted workshops on the role of ageing society for a transition to low-carbon technologies at the household level under the ‘**Women Buying Green**’ project that brought together experts from energy, environmental and behavioural economics fields and local industries (Jan 2019, Nov 2018).
- Five workshops were organised by CST under “**Zero in on NI Heat**” project to initiate public debates on heat decarbonisation in NI.
- GCRF Pump-Prime workshop on **Sustainable Design and Shared Space** (Jan 2018) in Ghana and **HERD Power workshop** in Gaborone, Botswana (Feb 2018).

Our research is disseminated through our undergraduate and postgraduate course provision. CST's energy research feeds directly to **BSc Energy and BEng Architectural Engineering programme** and **MSc in Renewable Energy & Energy Management** and new **MSc in Energy Storage programme** launched in 2019. FireSERT and HySAFER research outcomes directly influences the **MSc Fire Safety Engineering programme**. A new research based PgCertPD programme in **Hydrogen safety** has started from 2020.