中国光储直柔建筑发展战略路径研究

(二期)

Research on the Strategic Path of PEDF Buildings in China (Phase II)

综合课题

Comprehensive Report

中国光储直柔建筑战略发展路径研究项目组

2023 年 12 月 15 日

Project Team for Research on the Strategic Path of PEDF Buildings in China

Dec 15, 2023

致谢

本研究由清华大学统筹撰写，由能源基金会提供资金支持。

ACKNOWLEDGEMENT

This report is a product of Tsinghua University and is funded by Energy Foundation China.

免责声明

- 若无特别声明，报告中陈述的观点仅代表作者个人意见，不代表能源基金会的观点。能源基金会不保证本报告中信息及数据的准确性，不对任何人使用本报告引起的后果承担责任。
- 凡提及某些公司、产品及服务时，并不意味着它们已为能源基金会所认可或推荐，或优于未提及的其他类似公司、产品及服务。

Disclaimer

- Unless otherwise specified, the views expressed in this report are those of the authors and do not necessarily represent the views of Energy Foundation China. Energy Foundation China does not guarantee the accuracy of the information and data included in this report and will not be responsible for any liabilities resulting from or related to using this report by any third party.
- The mention of specific companies, products and services does not imply that they are endorsed or recommended by Energy Foundation China in preference to others of a similar nature that are not mentioned.

中国光储直柔建筑发展战略规划综合报告

在我国“2030 年之前实现碳达峰，2060 年力争实现碳中和”的目标背景下，实现能源革命、把以化石能源为基础的碳基能源系统转型为以可再生能源为基础的零碳能源系统是其中最为关键的任务。“光储直柔”建筑新型配电系统能够为上述关键任务提供有力支撑，使建筑在电力系统中从单一的消费者转型成为“产、消、调蓄”三位一体的新角色，从而有效解决发展新型电力系统时出现的缺少风电光电安装空间、缺少有效调蓄能力等关键问题。

在能源基金会的大力支持下，“中国光储直柔建筑发展战略路径研究”项目（2021.6-2022.6）通过一年的研究工作，对中国“光储直柔”的基础性研究、前瞻性政策分析与工程实践进行了探索，共设置 13 项课题，覆盖“光储直柔”系统的宏观政策研究与规划、关键技术研究与设备开发、标准体系研究、示范工程设计与实施以及综合管理与宣传推广。通过本项目支持的各项活动，使各级政府和有关部门开始关注“光储直柔”技术。国务院《2030 年前碳达峰行动方案》文件中明确写明“提高建筑终端电气化水平，建设集光伏发电、储能、直流配电、柔性用电于一体的‘光储直柔’建筑”。

目前，相关领域及部门均已认识到“光储直柔”这一新技术是建筑低碳发展的重要措施，进一步将对新型电力系统的发展提供有力支撑。如何顺着当前“光储直柔”的迅猛发展势头进一步深化落实，确保其核心理念和目标切实达成，将是下一阶段需要重点关注的问题。通过过去一年的研究，其中有诸多关键工作亟待开展：目前尚未建立起“光储直柔”的完备技术体系，亦缺少系列产品、系统设计方法与政策机制；现有的标准化体系尚需进一步迭代更新，并针对工作的轻重缓急，加速相关内容的编写落实；最重要的是，光储直柔的最终目的是协助电网有效消纳风电光电，但目前尚未有可操作的与电网协调互动的机制以及具体的设计运行方法。因此，“光储直柔”的下一阶段工作需要利用好目前的大好形势，抓住关键问题加以突破，引导各类工程明确目标并进行全周期引导，推出合适的政策机制并努力使其落实，从而保证“光储直柔”核心目标的顺利实现；进一步宣传推广，把示范项目从一幢建筑扩充到一个地区、一个城市，具体展示怎样通过“光储直柔”建立新型零碳的电力系统，从而在可靠电力供给前提下实现全区域的零碳能源革命。

本项目为“中国光储直柔建筑发展战略路径研究”项目（2021.6-2022.6）的二期项目，将对“光储直柔”在中国的发展与落地提供有力支撑。总结一期项目的成果与经验，二期项目的研究对象将分为五类（即综合、城市、农村、孤网系统、充电桩）。在每一个对象分类中，从模式政策技术类、标准规范类、工程示范类、综合推广类这四类角度设计研究内容并确立目标。具体如下：

1、综合：在建筑层面，根据其自身的源储荷特征，确立建筑光伏利的四

种模式（即“只进不出”、“只出不进”、“不进不出”和“有进有出”）及评价方法；在电网层面，提出可反映电力系统供需关系的动态碳排放责任因子方法，并确立技术上和政策上可操作的机制以及设计落地方法；在标准层面，完善落实光储直柔标准体系，解决体系内标准之间、体系外与相关领域国内外标准的协调问题；在示范层面，完成区域级的光储直柔设计规划方案并推动落地；在项目统筹层面，宏观协调项目内部各项研究内容，推动成果的宣传推广。

2、城市：提出城市建筑电力“只进不出”的技术方案、评价指标与经济模式；成立光储直柔工程咨询标准化模式与组织，促进相关工程项目全周期各环节的技术支持、工程指导与认定激励；完成城市光储直柔建筑工程案例集。

3、农村：全面调研农村供用电模式及农机具电气化情况，提出“农机具电气化+电池标准化”的模式和机制；提出农村电力“只出不进”的技术方案，包括农网调控方法和运行管理模式，研究给出可行的融资模式；完成农村电气化技术导则；完成村级电力系统“只出不进”的示范工程。

4、孤网系统：提出孤网系统电力“不进不出”的技术方案、评价指标与经济模式，研究该方案在“一带一路”推广以解决能源贫困问题的可行性及产生的影响；完成直流孤网系统技术导则，指导该系统的模块化、规模合理化产品；完成孤网系统工程示范。

5、充电桩：研究典型城市或区域的私家车辆行为特征，提出充电桩网络在不同规模区域布局的合理方案，提出从当前“通过可控充电就地消纳屋顶光伏并参与电网削峰”至远期“通过可控充放电支撑新型电力系统可再生能源消纳”的发展路径；提出充电桩网络在城市的会员制模式并进行技术经济性分析；以典型区域为例（如海南岛），完成智能充电桩网络参与零碳能源系统构建和调蓄的规划方案与示范工程。

执行摘要

1. 统筹中国光储直柔建筑发展战略路径研究（二期）设计与整体规划

- **中国光储直柔建筑发展战略路径研究（二期）共设置 9 个课题。**研究内容从两个维度进行划分，即研究对象（综合、城市、农村、孤网系统、充电桩）和研究方向（模式政策技术类、标准规范类、工程示范类、综合推广类）。其中，综合类包括课题 1“建筑光伏利用模式与建筑柔性用能评价方法”、课题 6“基于动态碳排放责任因子终端自律调节及碳交易机制研究”、课题 7“光储直柔相关标准建设与协同性研究”、课题 8“光储直柔区域级研究”；城市类包括课题 2“城市建筑光储直柔系统构建模式与示范”；农村类包括课题 3“农村光储直柔系统构建模式与示范”；孤网系统类包括课题 4“孤网系统光储直柔模式与示范”；充电桩类包括课题 5“电动车与建筑协同参与电网调节的潜力与模式”；综合推广类包括课题 9“中国光储直柔建筑发展战略规划综合报告”。以上 9 个课题涵盖“光储直柔”领域内的主要研究对象和应用场景，从政策、机制、技术、标准、示范、推广等各方面与一期项目构成承接关系，促进相关研究工作的进一步深化。研究成果将为“光储直柔”技术在我国全面落地应用提供实用的技术方案、有效的政策引导和完备的标准体系。

图 0 中国光储直柔建筑发展战略路径研究（二期）课题设置

2. 组织项目开题、中期、结题、专项研讨等会议，综合协调各课题研究进展

- **组织项目开题会议。**2022 年 10 月 12 日，由能源基金会支持、清华大学建筑节能研究中心牵头的《中国光储直柔建筑发展战略路径研究（二期）》项目开题会顺利召开。中国工程院原副院长杜祥琬院士、国家能源专家咨询委员会副主任白荣春、国家能源局原副局长吴吟、国家发展和改革委能源研究所原所长周大地、中国建筑节能协会副会长倪江波、中国电力企业联合会专家委员会副主任王志轩、中国能源研究会秘书长孙正运、农业农村部农业生态总站首席专家王全辉、亚洲开发银行前首席能源专家翟永平、中国建筑东北设计研究院郭晓岩大师、中国建筑设计研究院李俊民总工等特邀专家，住房与城乡建设部标准定额司建筑节能处林岚岚处长、孟光调研员等特邀嘉宾受邀参会指导项目。能源基金会总裁邹骥、项目副总裁李洁、能源基金会低碳城市项目主任王志高等，项目组成员清华大学建筑学院江亿院士、清华大学车辆学院欧阳明高院士及项目参与单位深圳建科院、南京国产直流配电有限公司、国创能源互联网创新中心（广东）有限公司、中科华跃能源互联网研究院、国网（苏州）城市能源研究院等十余家项目参与单位共计 100 余人参加了本次会议。

图 2 项目开题会议

- **组织项目专题研讨会。**为了推动该项目的顺利开展，2022 年 12 月 21 日和 2023 年 1 月 10 日分两组进行了第一阶段专题技术研讨会，2023 年 3 月 30 日开展第二阶段专题技术研讨会。能源基金会低碳城市项目王志高主任、高级项目主管赵言冰、项目经理付颖雨等，项目组成员清华大学建筑学院江亿院士、杨旭东教授、清华大学车辆学院王贺武研究员等及项目参与单位深圳市建筑科学研究院、国创能源互联网创新中心（广东）有限公司、中科华跃能源互联网研究院、国网（苏州）城市能源研究院、清华深圳国际研究院、南京国臣直流配电有限公司等十余家项目参与单位的 60 余人受邀参与了第一阶段项目专题技术研讨会。国网华北分部调度控制中心副主任刘一民、国网北京电力公司科技部主任张丽

等多位电力领域专家应邀出席本次研讨会，并与建筑领域多位专家共同研讨，协力推动双碳目标下的建筑、电力跨学科研究和深度融合。能源基金会总裁邹骥、低碳城市项目主任王志高、高级项目主管赵言冰、项目经理付颖雨，项目组成员清华大学江亿院士、杨旭东副院长等及项目参与单位深圳市建筑科学研究院、国创能源互联网创新中心（广东）有限公司、中科华跃能源互联网研究院、国网（苏州）城市能源研究院、清华深圳国际研究院、南京国臣直流配电有限公司等十余家项目参与单位的 60 余人受邀参与了第二阶段研讨会。

图 3 专题技术研讨会

- **组织项目中期会议。**2023 年 5 月 26 日，由能源基金会支持、清华大学建筑节能研究中心牵头的《中国光储直柔建筑发展战略路径研究（二期）》项目中期报告会在北京顺利举行。中期报告会邀请了建筑领域、能源电力领域的多位资深专家与会，包括全国能源基础与管理标准化技术委员会副主任白荣春、国家发展和改革委能源研究所原所长周大地、中国建筑节能协会副会长倪江波、国家电网有限公司科技部副主任许海清、国网北京市电力公司总工史景坚、中国能源研究会分布式能源专业委员会主任段洁仪、中国电力企业联合会副秘书长兼标准化中心主任刘永东、腾讯碳中和战略高级顾问翟永平、中国建筑设计院总工李俊民、中建西南设计院总工戎向阳、国网华北分部调控中心副主任刘一民、国网北京市电力公司科技部主任张丽等特邀专家，住房与城乡建设部标准定额司建筑节能处林岚岚处长、孟光调研员等特邀嘉宾受邀参会指导项目。能源基金会总裁邹骥、低碳城市高级项目主任王志高、高级项目主管赵言冰等，项目组成员清华大学江亿院士、副院长杨旭东教授等及项目参与单位深圳市建筑科学研究院、国创能源互联网创新中心（广东）有限公司、中科华跃能源互联网研究院、国网（苏州）城市能源研究院、清华大学深圳国际研究生院、南京国臣直流配电科技有限公司等十余家项目参与单位的 60 余人受邀参与本阶段项目交流会，协力推动双碳目标下的建筑、电力跨学科研究和深度融合。

图 4 项目中期会议

- **组织项目结题会议。**由能源基金会支持、清华大学建筑节能研究中心牵头的《中国光储直柔建筑发展战略路径研究（二期）》项目 9 个课题验收会，于 2023 年 10 月 12 日在清华大学举行。本次会议邀请了中国勘察设计协会电气分会会长欧阳东、中国能源研究会专家杨庆、中国家用电器研究院总工徐鸿、中国建筑设计院机电总工潘云钢、中国建筑设计院电气总工李俊民、农业农村部农业生态总站首席专家王全辉、北京电力科学研究院主任李香龙、北京交通大学重点实验室副主任童亦斌作为等特邀嘉宾受邀参会进行结题评审。

3. “光储直柔”宣传推广在公众号、 权威书籍、标准建设等方面取得显著进展

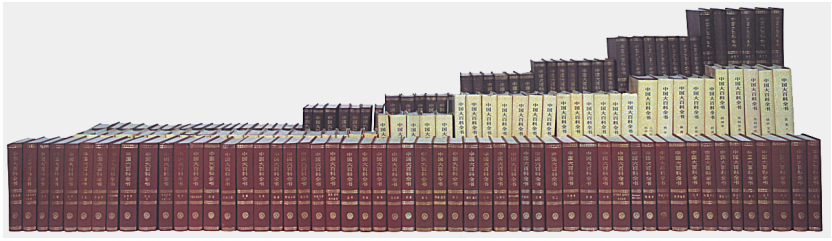
- **成立光储直柔专业委员会。**为推动国家“双碳”战略背景下城乡建设领域的绿色节能低碳发展，加强光储直柔领域专家队伍的建设。2022 年 10 月 18 日，专委会面向全行业征集光储直柔领域相关专家，并得到了行业的积极响应与支持。经过报名、审核、评选，第一批共入库 33 位专家，其中 52%来自设计研究院、18%来自高等院校、18%来自终端设备厂家、9%来自地产商、3%来自学协会。专委会将依托专家队伍，积极为行业开展服务。加速推进光储直柔行业发展，助力国家“双碳”战略目标的实现。

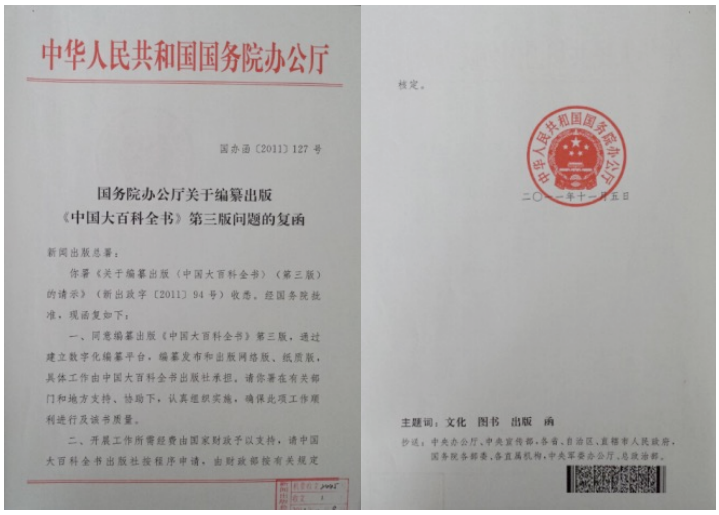
图 5 直流联盟公众号

- **发布直流建筑联盟公众号。**直流建筑联盟公众号自 2018 年 4 月发布以来，开设“直流百问”科普问答、“直流童话”现场讲堂、“明辩”现场讲堂、“桐你直行”直流现场讲堂四大板块，截至 2023 年 9 月为止，“直流百问”科普问答共发布近百问，累计访问人次达 36730 人次；三个系列现场讲堂共发布 22 期，累计访问人次已逾 87000 人次。

- **完善“光储直柔”标准体系建设，实现标准引领。**项目组积极推动光储直柔相关标准的编撰工作，以标准体系为引领，积极推动我国光储直柔”业的良性发展，项目组参编的国标、团标等标准 10 项，如表 2-4 所示。此外，中国建筑节能协会光储直柔专业委员会编写了《建筑光储直柔技术与工程案例》、《携手零碳-建筑节能与新型电力系统》等相关专著，从工程实际出发进一步引领我国光储直柔事业的发展。

- **《中国大百科全书》收录“光储直柔”词条。**《中国大百科全书》第三版(以下简称“第三版”)是在数字出版时代传统媒体与新媒体融合发展背景之下的大型综合性百科全书。第三版在中国大百科全书总编辑委员会领导下，由中国大百科全书出版社负责组织专家撰稿，编辑出版，将建设成为有中国特色、有国际影响力的权威知识宝库。《中国大百科全书》第三版中将“光储直柔”列入土木工程学科的词条，网络版已发布，纸质版正在印刷过程。





中华人民共和国国务院办公厅

国办函〔2011〕127号

国务院办公厅关于编纂出版
《中国大百科全书》第三版问题的复函

新闻出版总署：

你署《关于编纂出版〈中国大百科全书〉（第三版）的请示》（新出政字〔2011〕94号）收悉。经国务院批准，现函复如下：

一、同意编纂出版《中国大百科全书》第三版，通过建立数字化编纂平台，编纂发布和出版网络版、纸质版，具体工作由中国大百科全书出版社承担。请你署在有关部门和地方支持、协助下，认真组织实施，确保此项工作顺利进行及该书质量。

二、开展工作所需经费由国家财政予以支持，请中国大百科全书出版社按程序申请，由财政部按有关规定

核定。

二〇一一年十一月五日

主题词：文化 图书 出版 函

抄送：中央办公厅、中央宣传部，各省、自治区、直辖市人民政府，国务院各部委，各直属机构，中央军委办公厅、总政治部。

图 6 《中国大百科全书（第三版）》立项

- **“光储直柔”设计方法纳入行业权威设计手册。**建筑光储直柔系统设计方法纳入《实用空调供暖设计手册（第三版）》第 3 章能源应用部分。作为暖通空调设计“红宝书”，《实用空调供暖设计手册》于 1993 年出版第一版，至 2008 年修订发布第二版，如今进行第三版修编，编入了大量新技术、新方法、新设备、新材料的内容。光储直柔作为近年研究实践的可行的建筑零碳用电技术路径之一，纳入建筑能源应用将对建筑行业在工程设计方面的低碳绿色转型、实现“双碳”目标提供重要支撑。

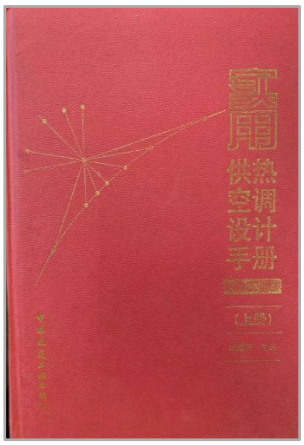


图 7 实用供暖空调设计手册

- **推动国家重点研发计划项目“建筑机电设备直流化产品研制与示范”**

立项。2023 年 2 月 7 日，由中国家用电器研究院牵头的“十四五”国家重点研发计划“建筑机电设备直流化产品研制与示范”项目启动暨实施方案论证会在京召开。项目联合清华大学和北京工业大学 2 所高校，以及中国电器科学研究院股份有限公司、珠海格力电器股份有限公司、青岛海尔智能技术研发有限公司、深圳市建筑科学研究院股份有限公司、公牛集团股份有限公司、中国特种设备检测研究院、中国建筑科学研究院有限公司等 7 家企事业单位共同承担。

图 8 “建筑机电设备直流化产品研制与示范”项目启动会现场

- **发表微信小程序与 PC 桌面端程序——光储直柔计算软件。**该计算工具以实现建筑电力交互为目标，采用城市电网、建筑光伏、建筑储能和用电负荷四者 8760 小时动态平衡的方法，用于建筑光储直柔项目基本容量配置方案及运行效果分析的辅助设计关键，在项目建设前期，设计师、业主、技术人员可以通过该软件进行系统建模、仿真计算、多目标运行优化，最终获得配置方案及运行特性，并可视化展示运行仿真结果，从而支撑光储直柔项目的方案设计与决策。

- 图 9 光储直柔计算软件

4. 完成综合报告

- **本项目聚焦中国光储直柔建筑发展战略路径，具体研究对象分为以下五类：综合、城市、农村、孤网系统、充电桩。**在对每一个对象分类中，从模式政策技术类、标准规范类、工程示范类、综合推广类这四类角度出发开展研究，给出相应对策与方案。综合类包括课题 1“建筑光伏利用模式与建筑柔性用能评价方法”、课题 6“基于动态碳排放责任因子终端自律调节及碳交易机制研究”、课题 7“光储直柔相关标准建设与协同性研究”、课题 8“光储直柔区域级研究”；城市类包括课题 2“城市建筑光储直柔系统构建模式与示范”；农村类包括课题 3“农村光储直柔系统构建模式与示范”；孤网系统类包括课题 4“孤网系统光储直柔模式与示范”；充电桩类包括课题 5“电动车与建筑协同参与电网调节的潜力与模式”；综合推广类包括课题 9“中国光储直柔建筑发展战略规划综合报告”。

- **课题 1** 聚焦建筑光伏利用模式与柔性评价方法，旨在揭示不同建筑场景中可再生电力的高效利用模式，给出建筑中柔性资源的统一刻画方法。本课题收集了不同气候区、不同类型建筑的全年用电数据，分析了建筑用电的日内、周内、季节波动情况，揭示了其与光伏发电曲线之间的不匹配程度。进一步根据建筑光伏的消纳情况，将光伏利用模式分为“只进不出”“只出不进”“不进不出”“有进有出”四类，并探究了不同光伏利用模式对储能和柔性调节的需求。为了统一设计配置建筑区域内的广义储

能，建立了刻画广义储能的“等效电池模型”，实现了柔性用能资源的量化描述，为建筑储能资源的高效利用路径探索奠定了理论基础与数据支撑。

- **课题 2** 聚焦城市光储直柔系统构建，旨在提出适用于城市建筑的光储直柔技术方案，并进行示范工程应用可行性论证。本课题基于课题 1 的研究成果，明确了城市条件下“只进不出”光储直柔技术方案的光伏消纳目标，并结合实际工程项目规划和设计对区域“光储直柔”系统应用进行方案规划，形成了经济合理的光储直柔配置方案。光储直柔工程方案咨询方面，课题组依托中国建筑节能协会光储直柔专业委员会，组建了跨行业的专家智库，对 6 项不同建筑类型（商业建筑、教育建筑、居住建筑和既有办公建筑改造等建筑类型）的光储直柔示范工程进行了专家论证，多角度揭示了光储直柔技术在不同类型建筑中应用的难点。光储直柔建筑示范应用方面，本课题通过全国范围不同气候区不同建筑类型的案例征集与重点项目现场调研，选择了 17 个案例示范工程，编制了光储直柔建筑案例集，邀请了项目建设者和行业内专家总计 80 余人参与案例集编制，形成了广泛的影响力，为规模化推动“光储直柔”建筑发展提供技术支撑和实践经验参考。

- **课题 3** 聚焦农村光储直柔电力系统构建，旨在推动农村碳中和目标的实现。本课题首先基于经济性和去中心化控制原则，提出了农村新型电力系统设计方案，在拓扑和设备参数的基础上，结合母线电压下垂控制的方法模拟电力系统的运行状况，验证了方案的合理性。上述设计方案已形成技术导则，并将对外公布。其次充分挖掘电动农机具的储能潜力，针对农机具电气化的现状、未来电动农机具储电能力预测、农机具电气化的社会效益、农机具电气化面临的挑战等四个方面展开调研，为我国电动农机具的储能潜力挖掘提供参考依据。再次，课题组对全国 7 个村庄进行了实地调研，并与罗盖村当地政府和国家电网公司达成合作意向，目前已完成示范村“光储直柔”电力系统投资和设计。最后，本课题对不同类型的融资方式以及收益进行了对比分析，并给出合适的融资建议，同时汇总分析了政府关于农村地区的相关政策，并根据农村新型电力系统面临的困境提出新的政策建议，进一步提高未来建设农村新型电力系统的经济性。

- **课题 4** 聚焦孤网光储直柔系统构建，旨在解决“一带一路”无电地区用电困难问题，推进“一带一路”建设进程。本课题基于应用场景分析和技术发展现状的调研，开展光储直柔孤网系统优化配置研究，根据用户需求（保障型、经济型和舒适型）和项目当地的连续阴雨天数，确定光伏系

统和储能系统的容量配置；通过市场调研分析，得到光储直柔系统建设投资成本和架空线路敷设投资成本，对比分析两者建设距离及建设成本的关系，指出建设光储直柔孤网系统的经济驱动力。本课题选择光伏未来屋直流社区、珠海荷包岛 5G 基站、纳木措圣象天门光伏驿站等多个应用场景，实证孤网光储直柔系统场景应用，挖掘技术方向，即通过实际工程应用，引导产业技术攻关，验证系统，给出技术建议案，为“一带一路”沿线无电地区的建设推进提供技术支撑与经验参考。

- **课题 5** 聚焦车辆与建筑的协同互动，旨在充分挖掘电动车作为建筑/电网用能和储能移动终端的应用潜力，实现对集中风光电、分布式光伏的高比率消纳。本课题基于城市尺度的私家车行为大数据，对典型城市的私家车行为的特征进行了分析，给出了深圳市充电负载的热度分布。进而提出智能充电桩分布式控制方法，通过模拟仿真方法研究智能充电桩在不同场景和尺度下的利用方式，计算其节能效果和经济性效益，并基于课题 6 的研究成果，提出利用碳排放责任因子进行车辆充放电调控，指出采用双向充电可降低 10.7%的需求侧碳排放。本课题分析了“免费充电，统一调度”的运营模式，对车与建筑协同参与电网调节这一方式的能源可靠性和经济可行性进行了验证，研究结果指出在此会员制模式下利用电动车电池作为储能，在住宅场景下和办公室场景下可以分别提高 57%与 52%的光伏利用率。完成了清华大学建筑节能楼等示范项目，可以用光伏满足 100%的电动车用电需求，平均光伏自消纳率可达 55%。

- **课题 6** 聚焦动态实时碳排放责任因子计算和零碳终端自律调节方法，旨在提出光储直柔建筑参与碳市场交易的途径和机制建议。本课题在国内外文献综述的基础上，基于促进电力系统供需平衡和降低电力系统碳排放的目标，提出基于用户侧承担碳排放责任的动态碳排放责任因子框架体系，及时反映电网供需关系，激励海量的、独立的、个性化的终端用户朝着目标方向行动。研究成果已在国网华北分部调控中心、北京市电力公司、家电厂商、电动车运营平台、楼宇能源管理聚合商全环节实现了全环节贯通。进而，课题组在光储直柔建筑的实践案例和碳排放责任因子的技术验证基础上，结合对国内碳交易政策梳理市场建设情况调研访谈，提出了建立电力市场与碳市场联动机制、形成电价与碳价有机融合体系的机制模式建议，充分发挥市场化机制在可再生能源发展中的激励作用。

- **课题 7** 聚焦光储直柔相关标准间的协同性，旨在总结光储直柔相关标准的共性技术问题、进行在编制/修订标准与光储直柔技术内容系统的协同性。课题组通过梳理了与“光储直柔”四项技术相关的 244 项标准，分

析了光储直柔当前应用存在的问题，传统思维下仅关注工程上“有没有”、“用没用”，鲜少关注用得结果“好不好”。光储直柔应以结果为导向，用系统的思维去构建新型系统。本课题进一步关注光储直柔的多学科、多领域、多行业融合需求，梳理了 54 项光储直柔需协同的工程标准，并先针对比较完善的建筑光伏标准体系，提出 12 项包含强制性标准和推荐性标准的规范协同建议，并撰写了 5 项制/修订的光储直柔相关条文内容，为进一步推进更多相关标准实现光储直柔内容的协同奠定了良好的基础。

- **课题 8** 聚焦光储直柔区域级应用可行性示范论证，旨在揭示该应用在清洁能源供给结构、电力负荷消费、主动平抑负荷峰值方面的优势潜力。本课题以苏州为典型区域案例，通过实地考察、调研等获取区域级电力供需数据，厘清了不同社会经济发展阶段下的电力供需关系变化特征。针对现有电力系统供需特征、未来电力需求发展规律，研究基于建筑光储直柔系统构建来推动零碳电力系统建设的技术方案，探索不同建筑主体中的光伏、储能及柔性负荷资源互补互济模式，提出面向建筑群的光储直柔系统利用解决技术方案。针对区域内的典型建筑或园区，选取典型案例开展光储直柔系统方案设计，研究光伏与建筑内负载有效结合的光伏发电就地利用消纳模式，研究可利用的直流负载接入光储直柔系统中的容量配置、与光伏发电相适应的运行调节策略，推动光储直柔系统示范工程建设。

- **课题 9** 聚焦光储直柔研究项目（二期）设计与整体规划，旨在高效高质量实现项目统筹管理，积极推动光储直柔宣传推广，并完成项目综合报告。本课题从“研究方向”与“研究对象”两个维度对本项目进行划分，将项目拆解成 9 个课题，把从工程实施过程中得到的新认识不断地反应到项目研究中来。建立项目办公室，负责课题协调联络；组织学术沙龙，针对具体专题组织课题组汇报并邀请外部专家点评；积极组织项目交流，根据研究进展不定期组织各课题之间的交流与讨论。建立直流建筑联盟，组织包括企业、研究机构、建设部门，共同开展“光储直柔”建筑宣传、开发、推广；筹办首届“光储直柔”大会，进一步壮大“光储直柔”声音；组织“光储直柔”专题技术论坛，不断更新、推动“光储直柔”技术的发展。汇总研究成果，形成综合报告，产出政策建议并提交有关部门，对“光储直柔”建筑发展与电力系统间的深入融合、需要的综合评价指标等提出发展方向。

Executive Summary

1. Research on the Strategic Path of PEDF Buildings in China (Phase II): Design and Overall Planning

- **The research on the Strategic Path of PEDF Buildings in China (Phase II) has set up a total of 9 research topics.** The research content is divided into two dimensions, namely the research object (comprehensive, urban, rural, isolated network system, charging pile) and the research direction (mode policy technology category, standard specification category, engineering demonstration category, comprehensive promotion category). Among them, the comprehensive category includes topic 1"Building-integrated Photovoltaic Utilization Patterns and Flexibility Evaluation Methods", topic 6 "Research on the self-discipline regulation method of the terminals and carbon emission permits trade mechanism based on the dynamic emission responsibility factor", topic 7 "Construction and coordination of related standards for PEDF systems", topic 8 "Regional Application and Demonstration of PEDF"; urban category includes topic 2 "Construction mode and demonstration of photovoltaic and storage directly flexible systems in cities"; rural category includes topic 3 "Construction mode and demonstration of PEDF systems in rural areas"; isolated network system category includes topic 4 "Construction mode and demonstration research of PEDF in isolated network system"; charging pile category includes topic 5 "Research on the energy flexibility potential of coordinating electric vehicles and buildings for grid regulation"; comprehensive promotion category includes topic 9 "Comprehensive report on strategic planning for the development of China's PEDF buildings". The above nine topics cover the main research objects and application scenarios in the field of "PEDF". They form a connection with the first phase project from policies, mechanisms, technologies, standards, demonstrations, and promotion aspects to further deepen relevant research work. The research results will provide practical technical solutions, effective policy guidance, and complete standard system for the comprehensive implementation and application of the technology in China.

Figure 1 Setting of topics for the development strategy path research of China's PEDF buildings (Phase II)

2. Coordinate the progress of research on each topic comprehensively

- **Organize the Kick-off Meeting for the Project.** The kick-off meeting for the second phase of the research project on the development strategy path of PEDF technologies, supported by the Energy Foundation and led by the Center for Building Energy Conservation Research at Tsinghua University, was successfully held on October 12, 2022. Special invited experts include: Academician Du Xiangwan, former Vice President of the Chinese Academy of Engineering; Bai Rongchun, Deputy Director of the National Energy Expert Advisory Committee; Wu Yin, former Deputy Director of the National Energy Administration; Zhou Dadi, former Director of the Energy Research Institute of the National Development and Reform Commission; Ni Jiangbo, Vice President of the China Building Energy Conservation Association; Wang Zhixuan, Deputy Director of the Expert Committee of the China Electricity Council; Sun Zhengyun, Secretary General of the China Energy Society; Wang Quanhui, Chief Expert of the Agricultural Ecosystems Station of the Ministry of Agriculture and Rural Affairs; Zhai Yongping, former Chief Energy Expert of the Asian Development Bank; Guo Xiaoyan, Master of Northeast Architectural Design Research Institute of China; Li Junmin, Chief Engineer of China Architectural Design Research Institute and other invited experts； Lin Lanlan, Director of Energy Efficiency Department, Standard Quota Department of Ministry of Housing and Urban-Rural Development and Meng Guang, Researcher, were invited as special guests to attend the meeting. Energy Foundation President Zou Ji, Vice President Li Jie, Director of Low Carbon Cities Project Wang Zhigao, members of the project team including academician Jiang Yi from Tsinghua University School of Architecture, academician Ouyang Minggao from the School of Automotive Engineering of Tsinghua University and more than 100 participants from participating units such as Shenzhen Institute of Building Research Co., Ltd, Nanjing Golden Cooperate DC Power Distribution Technology Co., Ltd, National Energy Internet Innovation Center (Guangdong) Co., Ltd, ZKHY

Energy Internet Research Institute Co., Ltd and State Grid (Suzhou) Urban Energy Research Institute were all present at this meeting.

- 

Figure 2 Kick-off Meeting of the Project

- **Conducted project thematic seminars.** In order to promote the smooth progress of the project, two groups held the first phase thematic technical seminars on December 21, 2022 and January 10, 2023, and the second phase thematic technical seminar was conducted on March 30, 2023. Wang Zhigao, Director of Low-Carbon City Project of the Energy Foundation, Senior Project Manager Zhao Yanbing, Project Manager Fu Yingyu, and other members of the project team, including academician Jiang Yi of Tsinghua University School of Architecture, Professor Yang Xudong, and researcher Wang Hewu of Tsinghua University School of Vehicle Engineering, as well as more than 60 participants from ten project participating units such as Shenzhen Institute of Building Research Co., Ltd, National Energy Internet Innovation Center (Guangdong) Co., Ltd., ZKHY Energy Internet Research Institute Co., Ltd, State Grid (Suzhou) Urban Energy Research Institute, and Tsinghua Shenzhen International Research Institute, Nanjing Golden Cooperate DC Power Distribution Technology Co., Ltd were invited to attend the first phase project thematic technical seminar. Liu Yimin, deputy director of dispatch and control center of North China Branch of State Grid, Zhang Li, director of science and technology department of Beijing Electric Power Company, and other experts in the field of electricity were invited to attend the seminar and jointly discuss with experts in architecture to promote interdisciplinary research and deep integration of buildings and electricity under the dual carbon target. President Zou Ji of the Energy Foundation, Director Wang Zhigao of Low-Carbon City Project, Senior Project Manager Zhao Yanbing, Project Manager Fu Yingyu, academician Jiang Yi of Tsinghua University School of Architecture, Vice Dean Yang Xudong, and more than 60 participants from ten project participating units such as Shenzhen Institute of Building Research Co., Ltd, National Energy Internet Innovation Center (Guangdong) Co., Ltd., ZKHY Energy Internet Research Institute Co., Ltd, State Grid (Suzhou) Urban Energy Research Institute, Tsinghua Shenzhen International Research Institute, Nanjing Golden Cooperate DC Power Distribution Technology Co., Ltd. were invited to attend the second phase seminar.

- 


Figure 3 Thematic Technical Seminar

- **Conducted mid-term project meeting.** On May 26, 2023, the mid-term report meeting of the project "Research on Development Strategies Path of China's PDEF Buildings (Phase II)" supported by the Energy Foundation and led by the Center for Building Energy Conservation Research of Tsinghua University was successfully held in Beijing. The meeting invited several senior experts from the fields of architecture and energy and power to attend, including Bai Rongchun, deputy director of the National Energy Basic Management Standardization Technical Committee; Zhou Dadi, former director of the Energy Research Institute of the State Development and Reform Commission; Ni Jiangbo, vice president of the China Building Energy Conservation Association; Xu Haiqing, deputy director of the Science and Technology Department of State Grid Corporation of China; Shi Jingjian, Chief Engineer of State Grid Beijing Electric Power Company ; Duan Jieyi, director of the Distributed Energy Professional Committee of China Energy Research Society; Liu Yongdong, deputy secretary general and director of the Standardization Center of China Electricity Council; Zhai Yongping, senior consultant of Tencent Carbon Neutrality Strategy; Li Junmin, chief engineer of China Architectural Design Institute; Rong Xiangyang, chief engineer of Central Southwest China Architectural Design Institute; Liu Yimin, deputy director of the dispatch and control center of North China Branch of State Grid; Zhang Li, director of the Science and Technology Department of State Grid Corporation of Beijing; Lin Lanlan, Director of Energy Efficiency Department, Standard Quota Department of Ministry of Housing and Urban-Rural Development and Meng Guang, Researcher were invited as special guests to attend and guide the project. President Zou Ji, Senior Project Director Wang Zhigao, Senior Project Manager Zhao Yanbing, members of the project team such as academician Jiang Yi of Tsinghua University School of Architecture and vice dean Yang Xudong, and more than 60 participants from ten project participating units such as Shenzhen Institute of Building Research Co., Ltd, National Energy Internet Innovation Center (Guangdong) Co., Ltd., ZKHY Energy Internet Research Institute Co., Ltd, State Grid (Suzhou) Urban Energy Research Institute, Tsinghua Shenzhen International Research Institute, Nanjing Golden Cooperate DC Power Distribution Technology Co., Ltd. were invited to attend this stage project exchange meeting to jointly promote interdisciplinary research and deep integration of buildings and electricity under the dual carbon target.

Figure 4 Mid-term Meeting of the Project

- **Organize the project completion meeting.** The acceptance meeting of nine topics of the project "Research on Development Strategies Path of China's PEDF Buildings (Phase II)" supported by the Energy Foundation and led by the Center for Building Energy Conservation Research of Tsinghua University was held at Tsinghua University on October 12, 2023. This meeting invited Ouyang Dong, President of the Electrical Branch of China Survey and Design Association; Yang Qing, an expert from China Energy Research Society; Xu Hong, Chief Engineer of China National Appliances Research Institute; Pan Yungang, Chief Engineer of Mechanical and Electrical Engineering Department of China Architectural Design Institute; Li Junmin, Chief Engineer of Electrical Engineering Department of China Architectural Design Institute; Wang Quanhui, Chief Expert of Agricultural Ecology Station of Ministry of Agriculture and Rural Affairs; Li Xianglong, Director of Beijing Electric Power Research Institute; and Tong Yibin, Deputy Director of Key Laboratory of Beijing Jiaotong University as special guests invited to attend the meeting for project completion review.

3. Promotion and promotion of “PEDF”

- **Establish PEDF Professional Committee.** In order to promote green, energy-saving, and low-carbon development in the field of urban and rural construction under the background of the "double carbon" strategy of the country, we need to strengthen the construction of the expert team in the field of light storage and directly soft. On October 18th, 2022, the professional committee solicited experts from the whole industry in the field of PEDF, which received a positive response and support from the industry. After registration, examination, and selection, a total of 33 experts were included in the first batch, including 52% from design research institutes, 18% from institutions of higher learning, 18% from terminal equipment manufacturers, 9% from real estate developers, and 3% from academic associations. The professional committee will rely on the expert team to actively provide services for the industry. It will accelerate the development of the light storage and directly soft industry and help achieve the national "double carbon" strategic goal.

Figure 5 Direct-Current Alliance WeChat Official Account

- **Release the WeChat public account of DC Building Alliance.** Since its launch in April 2018, the WeChat public account of DC Building Alliance has set up four major sections: "DC 100 Questions" popular science Q&A, "DC Fairy Tales" live lecture, "Clear and Reasonable" live lecture, and "Purely Yours" DC live lecture. As of September 2023, there have been nearly 100 questions in the "DC 100 Questions" section, with a total of 36,730 visits; three series of live lectures have been published for 22 issues, with a total of more than 87,000 visits.
- **Improve the construction of "PEDF" standard system to achieve standard guidance.** The project team actively promotes the compilation of relevant standards for the field of PEDF, taking the standard system as the guide to actively promote the benign development of China's "PEDF" industry. The project team has participated in the compilation of national standards, group standards, and other standards, totaling 10 items, as shown in Table 2-4 . In addition, the China Building Energy Conservation Association PEDF Professional Committee has compiled related monographs such as 《Building Light Storage and Directly Soft Technology and Engineering Case》and《Hand in Hand Zero Carbon - Architectural Energy Conservation and New Power System》to further guide the development of China's PEDF industry from a practical engineering perspective.
- **The Chinese Encyclopedia includes an entry on "PEDF".** The third edition of the Chinese Encyclopedia (hereinafter referred to as the third edition) is a large-scale comprehensive encyclopedia under the background of the integration of traditional media and new media in the digital publishing era. Under the leadership of the General Editorial Committee of the Chinese Encyclopedia, the third edition is organized and edited by the China Encyclopedia Publishing House, with the aim of becoming an authoritative knowledge repository with Chinese characteristics and international influence. In the entry on "PEDF" in the third edition of the Chinese Encyclopedia, it is included in the discipline of civil engineering, and the online version has been published while the print version is in the printing process.

Figure 6 Project Initiation of Chinese Encyclopedia (Third Edition)

- **The "PEDF" design method is included in the authoritative design handbook of the industry.** The design method of building PEDF system is included in Chapter 3 of the Practical Air Conditioning Heating Design Handbook (third edition). As a "red book" in HVAC design, the Practical Air Conditioning Heating Design Handbook was first published in 1993, revised and released in 2008, and now under revision for the third edition, which includes a large number of new technologies, methods, equipment, and materials. As one of the feasible technical paths for zero-carbon electricity generation in buildings in recent years, the inclusion of PEDF in the application of building energy will provide important support for the low-carbon green transformation of the construction industry in engineering design and the realization of the "double carbon" target.

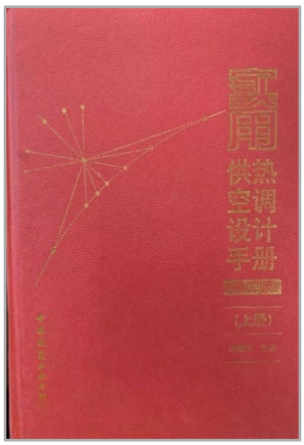


Figure 7 Practical Heating and Air Conditioning Design Manual

- 

Figure 8 "Starting Meeting of Research and Demonstration of DC Products for Building Electrical and Mechanical Equipment" project

- **Promote the establishment of the National Key R&D Program "Research and Demonstration of DC Products for Building Electrical and Mechanical Equipment".** On February 7, 2023, the project "Research and Demonstration of DC Products for Building Electrical and Mechanical Equipment" initiated by the China Academy of Home Appliances as part of the 14th Five-Year Plan was held in Beijing to discuss the implementation plan. The project is jointly undertaken by Tsinghua University and Beijing University of Technology, as well as seven enterprises and institutions including China Electrical Machine Research Institute Co., Ltd., Zhuhai Gree Electric Appliances Co., Ltd., Qingdao Haier Intelligent Technology Research and Development Co., Ltd., Shenzhen Construction Science Research Institute Co., Ltd., Bull's Group Co., Ltd., China Special Equipment Testing and Research Institute, and China Architecture Science Research Institute Co., Ltd.

- **Published WeChat mini-program and PC desktop program——"PEDF Calculation Software".** This calculation tool aims to achieve building power interconnection by adopting the method of dynamic balance between urban power grid, building photovoltaics, building energy storage and electricity load for 8760 hours, which is used as an auxiliary design key for basic capacity configuration scheme and operation effect analysis of building PEDF projects. In the early stage of project construction, designers, owners, and technicians can use this software to carry out system modeling, simulation calculation, multi-objective operation optimization, and ultimately obtain configuration schemes and operating characteristics. The simulation results are visualized to support the

plan design and decision-making of light storage and direct soft projects.

Figure 9 PDEF Calculation Software

4. Completion of the Comprehensive Report

- **This project focuses on the development strategy path of PEDF buildings in China, with specific research objects divided into five categories: comprehensive, urban, rural, standalone systems, and charging piles.** In each object classification, research is conducted from four perspectives: model policy technology, standard specification, engineering demonstration, and comprehensive promotion, giving corresponding strategies and solutions. The comprehensive category includes Topic 1 " Building-integrated Photovoltaic Utilization Patterns and Flexibility Evaluation Methods ", Topic 6 " Research on the self-discipline regulation method of the terminals and carbon emission permits trade mechanism based on the dynamic emission responsibility factor", Topic 7 " Construction and coordination of related standards for PEDF systems ", and Topic 8 " Regional Application and Demonstration of PEDF"; the urban category includes Topic 2 " Construction mode and demonstration of photovoltaic and storage directly flexible systems in cities"; the rural category includes Topic 3 "Construction mode and demonstration of PEDF systems in rural areas"; the standalone system category includes Topic 4 " Construction mode and demonstration research of PEDF in isolated network system"; the charging pile category includes Topic 5 " Research on the energy flexibility potential of coordinating electric vehicles and buildings for grid regulation"; the comprehensive promotion category includes Topic 9 "Comprehensive report on strategic planning for the development of China's PEDF buildings".

- **Topic 1** focuses on the utilization mode of building photovoltaics and flexible evaluation methods, aiming to reveal the efficient utilization mode of renewable

power in different building scenarios and provide a unified method for characterizing flexible resources in buildings. This topic collected annual electricity usage data from different climatic zones and types of buildings, analyzed the daily, weekly, and seasonal fluctuations of building electricity consumption, and revealed the degree of mismatch between them and photovoltaic power generation curves. Further, based on the absorption situation of building photovoltaics, the photovoltaic utilization mode was divided into four categories: "self-consumption buildings" "self-sufficient buildings " " islanded buildings " and " buildings that interact bidirectionally " The different photovoltaic utilization modes were explored for their demand on energy storage and flexible adjustment. In order to unify the design and configuration of generalized energy storage within the building area, an "equivalent battery model" was established to describe the generalized energy storage, realizing the quantitative description of flexible energy resources, laying a theoretical basis and data support for exploring the efficient utilization path of building energy storage resources.

- **Topic 2** focuses on the construction of urban PEDF systems. The aim is to propose an applicable technology plan for urban buildings, and to demonstrate the feasibility of engineering applications. This topic builds upon the research results of Topic 1, which clarified the photovoltaic energy absorption target for "self-consumption buildings" PEDF systems under urban conditions. Based on actual project planning and design, a regional "PEDF systems" application plan was formulated, resulting in an economically reasonable configuration plan for PEDF systems.In terms of consultation for PEDF system projects, the research team relied on the China Building Energy Conservation Association PEDF Systems Committee to form an inter-industry expert think tank. Experts from six different types of buildings (commercial, educational, residential, and renovation of existing office buildings) were consulted to conduct expert demonstrations for six different types of PEDF systems. This approach revealed multiple perspectives on the challenges of applying PEDF technologies in different types of buildings.In terms of demonstrating the application of PEDF systems in buildings, this topic collected case studies from different climate zones across the country for different building types through a nationwide survey. A total of 17 case demonstration projects were selected, and a collection of PEDF system case studies was compiled. A total of over 80 participants, including project builders and industry experts, were invited to participate in the compilation of the case study collection, resulting in widespread influence. This provides technical support and practical experience reference for promoting the development of "PEDF systems" architecture at a large scale.

- **Topic 3** focuses on the construction of rural PEDF power systems, aiming to promote the realization of carbon neutrality targets in rural areas. This topic first proposed a new rural power system design plan based on economic feasibility

and decentralized control principles. On the basis of topology and equipment parameters, combined with bus voltage droop control methods, the simulation of power system operating conditions was carried out to verify the rationality of the proposed plan. The above design plan has been formed into technical guidelines and will be released externally. Secondly, the potential energy storage capacity of electric agricultural machinery was fully explored. Four aspects were investigated, including the current status of electricalization of agricultural machinery, future prediction of electricity storage capacity of electric agricultural machinery, social benefits of electricalization of agricultural machinery, and challenges faced by electricalization of agricultural machinery. This provides a reference for exploring the potential energy storage capacity of electric agricultural machinery in China. Thirdly, the research team conducted field research in seven villages nationwide and reached a cooperation intention with the local government and State Grid Corporation in Luogai Village. At present, demonstration projects of "PEDF" power systems in Luogai Village have been completed. Finally, this topic compares and analyzes different types of financing methods and returns, provides appropriate financing recommendations, summarizes and analyzes relevant government policies for rural areas, and proposes new policy suggestions based on the difficulties faced by rural photovoltaic and storage power systems. This further improves the economic feasibility of future construction of rural PDEF power systems.

- **Topic 4** focuses on the construction of off-grid PEDF systems to address the electricity access difficulties in "Belt and Road" unelectrified areas and promote the progress of "Belt and Road" construction. This topic, based on the analysis of application scenarios and technical development status, carries out research on the optimal configuration of off-grid PEDF systems. According to user needs (security, economy, and comfort) and continuous cloudy days in the project area, the capacity allocation of PEDF systems is determined. Through market research analysis, the cost of constructing PEDF systems with direct power generation capabilities is obtained, and the relationship between the construction cost of photovoltaic and storage systems and the distance between them is compared. The economic driving force of building off-grid PEDF systems with direct power generation capabilities is pointed out. This topic selects several application scenarios such as DC communities for future houses, 5G base stations in Zhuhai Hebao Island, and solar energy stations in Namtso Shengxi Temple. It empirically applies off-grid PEDF systems to excavate technological directions. Through actual engineering applications, it guides industrial technology research and development, verifies systems, provides technical proposals, and provides technical support and experience reference for the construction of unelectrified areas along the "Belt and Road".

- **Topic 5** focuses on the synergy between vehicles and buildings, aiming to fully tap the application potential of electric vehicles as energy-saving and energy-

storage mobile terminals for buildings/grids, and achieve high-rate absorption of concentrated wind power, distributed photovoltaic, and other renewable energy. This topic analyzes the characteristics of private car behavior in typical cities at the urban scale based on big data, and provides a heat distribution of charging load in Shenzhen. It then proposes a distributed control method for smart charging piles, studies the use of charging piles under different scenarios and scales through simulation and simulation methods, calculates their energy-saving effects and economic benefits, and proposes using carbon emission responsibility factors to regulate vehicle charging discharge based on the research results of Topic 6. The topic points out that bidirectional charging can reduce demand-side carbon emissions by 10.7%.This topic analyzes the "free charging, unified dispatch" operation mode, verifies the energy reliability and economic feasibility of vehicles participating in grid regulation with buildings in this way, and concludes that using electric vehicle batteries as energy storage under membership-based model can increase the photovoltaic utilization rate by 57% and 52% in residential and office scenarios, respectively. The research results show that the demonstration project of Tsinghua University Building Energy Conservation Building can meet the electricity demand of all electric vehicles with photovoltaic power, and the average self-absorption rate of photovoltaic can reach 55%.

- **Topic 6** focuses on dynamic real-time carbon emission responsibility factor calculation and zero-carbon terminal self-regulation methods, aiming to propose suggestions on the ways and mechanisms for photovoltaic and storage buildings to participate in carbon market transactions. Based on domestic and foreign literature reviews and the goal of promoting the balance of power system supply and demand and reducing carbon emissions in power systems, this topic proposes a dynamic carbon emission responsibility factor framework system based on user side carbon emission responsibility, which can reflect the relationship between power system supply and demand in a timely manner and motivate massive, independent, and personalized terminal users to take action towards the target direction. The research results have been fully implemented in all aspects of the North China Dispatch Center of State Grid Huabei, Beijing Power Company, household appliance manufacturers, electric vehicle operation platform, building energy management aggregator, etc. On the basis of practical cases of photovoltaic and storage buildings and technical verification of carbon emission responsibility factors, combined with a review of domestic carbon trading policies and market construction survey interviews, this topic proposes mechanism models for establishing a linkage mechanism between electricity markets and carbon markets, forming an organic integration system of electricity price and carbon price, giving full play to the incentive role of market-oriented mechanisms in renewable energy development.

- **Topic 7** focuses on the synergy between relevant standards of PEDF technologies,

aiming to summarize common technical issues related to standards for PEDF technologies and to conduct synergy between the compilation/revision of standards and the technology content system. The research team has combed through 244 standards related to the "PEDF" four technologies, analyzed the problems existing in the current application of photovoltaic and storage technologies, and paid less attention to the results of their use under traditional thinking, focusing more on whether they exist or not, rather than how well they are used. PEDF should be guided by results, and a systematic thinking approach should be taken to build new systems. This topic further focuses on the multidisciplinary, multi-domain, and multi-industry integration needs of photovoltaic and storage technologies, combs out 54 engineering standards that need to be coordinated for PEDF technologies, and proposes 12 normative coordination suggestions including mandatory standards and recommended standards based on the relatively complete building photovoltaic standards system. It also wrote five contents related to the revision of laws and regulations related to PEDF technologies, laying a good foundation for further promoting the coordination of other related standards to achieve the content of PEDF technologies.

- **Topic 8** focuses on the demonstration and feasibility of regional applications of PEDF technologies, aiming to reveal the potential advantages of this application in terms of clean energy supply structure, electricity load consumption, and proactive load peak regulation. This topic takes Suzhou as a typical regional case and obtains regional-level power supply and demand data through field visits, surveys, etc. It clarifies the characteristics of power supply and demand changes under different stages of socio-economic development. Based on the current power system supply and demand characteristics and future development rules of electricity demand, this topic studies technical solutions for promoting the construction of zero-carbon power systems by constructing building PEDF systems. It explores complementary and mutually beneficial modes of photovoltaic, storage, and flexible load resources among different building entities and proposes technical solutions for the use of PEDF systems in buildings. For typical buildings or parks in the region, typical cases are selected to carry out design of PEDF system plans, study the local utilization of photovoltaic power generation combined with building loads, study the capacity allocation of available DC loads that can be connected to the PEDF systems, and study operation adjustment strategies that are compatible with the output of photovoltaics to promote the construction of demonstration projects of PEDF systems.

- **Title 9** focuses on the design and overall planning of the second phase of the research project on PEDF technologies, aiming to effectively and efficiently achieve integrated project management, actively promote the promotion of PEDF technologies, and complete a comprehensive report on the project. This topic

divides the project into nine topics from two dimensions: "research direction" and "research object", and continuously reflects new understandings obtained from the engineering implementation process into the project research. A project office is established to coordinate and contact the subjects; academic salons are organized to organize subject group reports and invite external experts to comment on specific topics; active organization of project exchanges is carried out at irregular intervals based on research progress, and interdisciplinary communication and discussion among each topic is promoted. A direct current building alliance is established to jointly carry out the promotion, development, and promotion of "PEDF technologies" in building construction; the first "PEDF technologies" conference is organized to further strengthen the voice of "PEDF technologies"; and thematic technical forums on "PEDF technologies" are organized to continuously update and promote the development of "PEDF technologies". The research results are summarized to form a comprehensive report, produce policy recommendations, and submit them to relevant departments, proposing development directions for the deep integration between the development of "PEDF technologies" buildings and power systems, as well as comprehensive evaluation indicators needed.